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ON A SIMPLE DIRECT METHOD OF DETERMINING THE CURVATURES OF SMALL LENSES.

PAPER BY MR. C. V. DRYSDALE, *Member.*

Read before the Optical Society on November 15th, 1900.

WHEN I was asked by the energetic Secretary, Mr. Salt, to give a paper on this date I was unaware that it would be the first paper of the season, otherwise I should have preferred that it had come from someone better fitted for the task. I trust, however, that although the subject I am about to deal with appeals specially to a certain section of the optical trade, it may not be without general interest.

About two years ago, when I was endeavouring to obtain information concerning the curves of various lenses for the information of my students, I was struck with the fact that no method of easily determining the curves of such lenses was described in optical books. On enquiry in the Trade I was surprised to find that no accurate method of measuring such curves appeared to be known, and I immediately set to work to devise such a method, the result being to obtain one, which although absurdly simple in principle, appears to be very convenient in practice, and to be capable of measuring the curvature of any spherical or cylindrical surfaces, from quite shallow curves to those of less than a millimeter radius.

Before describing this method it may be well to give a short account of the processes of measuring curvatures hitherto known, and which are applicable to surfaces of small radii.

Methods of Determining Curvatures at Present in Use.

The first of these is by means of the spherometer or its companion instrument, the lens measurer, the former of which is very accurate for curves of large radius, and, in the direct reading form devised by Dr. S. P. Thompson, very convenient. These instruments are, however, totally inapplicable for curves of small radius, as in this case the instrument would in the first place have to be of exceedingly small dimensions, and secondly, the calculations involved would be

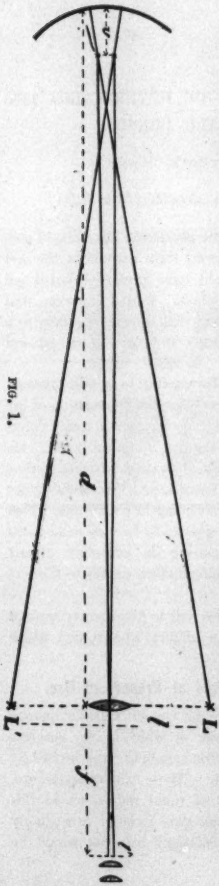


FIG. 1.

troublesome. In fact it may be said that the spherometer is unsuitable for curves of less than one inch in radius.

The method which seems to be most generally adopted in the trade for small lenses is to employ small sheet metal gauges turned to various diameters which are accurately measured with micrometer calipers. These gauges are applied to the grinding tool or to the lens, but it is obvious that no great accuracy can be expected from such a test.

A great refinement on the last method is that first adopted by the firm of Zeiss, of Jena, and which is now being adopted by several of the foremost English Opticians. This is to employ standard glass test plates ground to the curves, and to test the coincidence of the lens surfaces with these, by observing the interference rings produced when they are brought into contact. This method is undoubtedly the most accurate that can be employed, but it suffers from the disadvantage of having to keep a large and expensive stock of test plates of various radii, and the calculations involved in ascertaining the curvature of any intermediate surface from the diameter of the interference rings are very troublesome. Moreover, the determination of the curvature of the standard plates in the first instance is in itself a difficulty.

The only optical method hitherto known, applicable to the determination of the curvature of surfaces of small radii, which I have been able to trace, is one in which the distance between the images of two sources of light at a

known distance apart are observed by means of a telescope. The smaller the radius of curvature of the surface, the closer obviously will these images be. As this method does not appear to be well known in the trade, and it may be sometimes of service, it may not be out of place to give the formula for its use.

In fig. 1, let L and L′ be two sources of light separated by a distance l, T, a telescope provided with a micrometer eye-piece S, the surface to be tested; let also d represent the distance between the lamps and mirror, v the distance between the mirror and the image, r the radius of the mirror, and l' the distance between the images formed in the focal plane of the telescope, the focal length of the object glass being f. Then we have

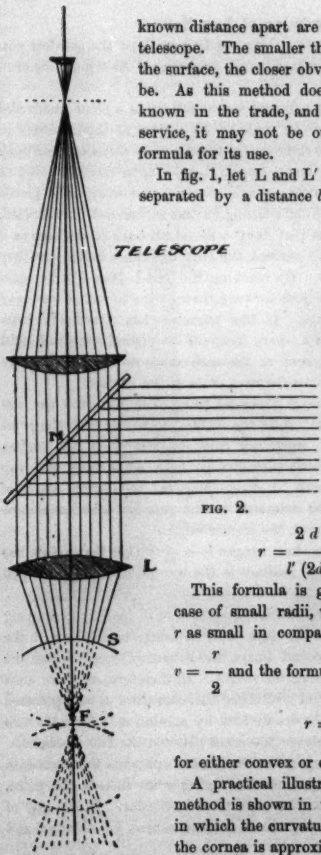


FIG. 2.

$$r = \frac{2\,d\,l'\,(d-f)}{l'\,(2d-f)+f\,l}$$

This formula is greatly simplified in the case of small radii, where we may take v and r as small in comparison with d, in this case $v = \frac{r}{2}$ and the formula becomes

$$r = \frac{2\,d^2}{f\,l}\,l'$$

for either convex or concave surfaces.

A practical illustration of the use of this method is shown in the corneal astigmometer in which the curvature of different sections of the cornea is approximately shown by observing the images of two white index marks in a telescope.

Description of New Method.

As above stated the method here put forward is of the greatest possible simplicity, and a few words will be sufficient to explain its principle.

Let parallel light from a distant source fall upon a plane unsilvered mirror M (fig. 2) placed at an angle of 45°; some of the light will be reflected, still parallel, at right angles to its former direction, and may be converged by an ordinary convex lens, L to a focus F. Let us suppose any reflecting surface, plane, concave or convex, to be placed at the point F, the rays of light falling on this surface will be reflected, and it is perfectly obvious that they will return back to the lens as if they had come from the surface, the only difference being that they have exchanged positions. On reaching the lens L they will be again rendered parallel and will pass forward through the mirror M and may be received in a telescope. If this telescope has previously been focused for parallel rays a sharp image of the distant source of light will be seen. The curvature of the surface has no effect on the size or sharpness of the image, as the rays cross at the surface.

Next suppose the surface S if convex to be brought nearer the lens L until the centre of curvature of the surface coincides with the point F, it is then evident that every ray from the lens meets the surface normally, and the light will therefore go back as it came, each ray returning along its old path; a sharp image of the distant source of light must be seen in the telescope in this case also, the image now being inverted compared with the former one.

In order to obtain the two images it is clear that the surface has been moved from the first position to the second by a distance equal to its radius of curvature.

If, on the other hand, the surface is concave, it is clear that removing the surface further from the lens until its centre coincides with the point F will give the second image, the distance through which the surface is moved again giving the radius. If, therefore, we have such a system of telescope, mirror and lens, the curvature of any polished surface may be immediately determined by moving it to form the two images and finding the distance traversed between the two positions.

When the surfaces are cylindrical instead of spherical the procedure is identical, one of the images, however, being a line instead of a point, this line being parallel to the axis of the cylinder. In the case of sphero-cylindrical surfaces two lines will, of course, be obtained and the two radii directly given.

Apparatus.

Although the above description is sufficient for anyone to make use of the method, it may be well to see how it may be readily carried out.

Figs. 8 and 8A shows the rough arrangement used by the author in connection with a simple student's microscope, the only attachments necessary being a plane unsilvered mirror mounted in a small cell (fig. 4)* which can be interposed between the microscope tube and the ordinary objective, and a scale with vernier to read off the radii. It is con-

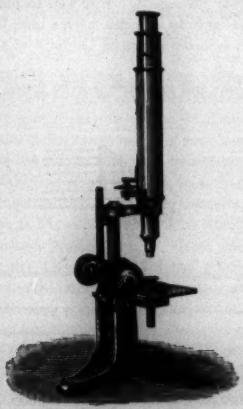


FIG. 8.

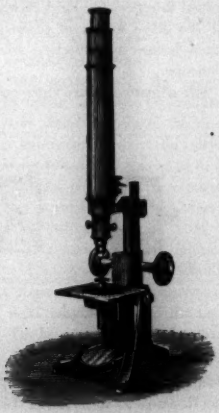


FIG. 8A.

venient also to have some form of clip to hold the lens or surface tested, but this is not necessary. In order to use this arrangement a telescope should be substituted for the ordinary eyepiece of the microscope, but for measurements of ordinary accuracy it is found quite sufficient to separate the lenses of the ordinary Huyghen's eyepiece sufficiently

* A somewhat similar device, using a prism instead of a mirror, was introduced, I believe, by Messrs. Beck, for illuminating objects from above This arrangement will serve for the purpose, but not so well as the unsilvered mirror as it cuts off the return rays.

to focus for parallel rays. The lower lens may conveniently rest on a stop in the microscope body, while the upper one can be raised or lowered to focus. The microscope is now set up opposite any convenient small source of light at a distance of some 10 ft. away (although 2 ft. or 3 ft. is sufficiently accurate for large curvatures), the mirror attachment screwed in place, and the mirror turned upwards so as to reflect the rays from the source of light directly into the telescope. The focusing of the telescope can thus be easily effected.

An ordinary object glass of somewhat greater focal length than the radius to be tested is next screwed into its place, and the mirror turned to reflect the light downwards through it. It is well to place on the stage a slip of plane glass and to turn the mirror until the image formed by reflection from it is in the centre of the field of the telescope.

The adjustments are then complete, and any surface to be tested is

FIG. 4.

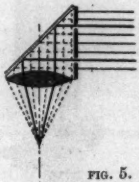


FIG. 5.

simply placed on the microscope stage and the microscope racked up and down so as to form the two images successively, the readings on the scale being taken in each case. The difference between these readings is, of course, the radius of curvature.

In order to obviate the necessity for any calculation whatever the surface may conveniently be supported on a stand which can be raised and lowered. The microscope scale is then set to zero, the surface raised or lowered until one of these images is formed, and the microscope racked up or down to obtain the second image. The scale reading then gives the radius of curvature directly, or if preferred a scale reading directly in diopters can be substituted.

In using this or any optical method for obtaining the curvature of

lens faces, some confusion may arise from the reflections at the posterior surface of the lens. To avoid this the obvious course is to cover the back of the lens with some backing material, as used for photographic plates. The author has used the "Avery" backing for this purpose with good results, or a drop of Canada Balsam and lamp-black will answer equally well.

Conditions Necessary to Secure Accuracy.

As for microscope work it may be of value to determine the curvatures with a considerable degree of accuracy, it is worth while giving a little attention to the conditions necessary to secure it.

In the first place it will be noticed that the converging lens should be truly achromatic and aplanatic, otherwise it will not bring the light to a point. Of course good quality microscope objectives are very carefully corrected in these respects, and consequently the results obtained by them are fairly reliable. In order, however, to eliminate any possible errors of this description, and also those due to depth of focus in the telescope, it is convenient to interpose between the mirror and the source of light a diaphragm having two small apertures in it. Instead of then working to a sharp focus the positions are found in which the two images are coincident, any errors of spherical aberration in the objective are thus eliminated as only a particular zone of the lens is employed. A great increase of accuracy is also obtained in the determination of the points, the lens system being virtually converted into a very sensitive range finder. To avoid chromatic aberration a monochromatic source of light may be used, or the light may be obtained from a spectroscope. The telescope should, of course, be properly corrected, but if the above diaphragm and monochromatic light are employed, it will be seen that any errors in it are not of consequence, in fact, the whole optical system may be made of uncorrected lenses under these circumstances.

The author has not had any opportunity of testing the accuracy of the method beyond using it with a vernier reading to $\frac{1}{10}$th of a millimeter or about $\frac{1}{2\,5\,4\,0}$th of an inch. From the ease with which these measurements can be made, however, there seems to be no reason to doubt that a very high order of accuracy may be obtained, something of the order of a ten-thousandth of an inch.

Determination of the Figure of a Lens.

As is well known, microscope lenses are frequently figured—*i.e.* their curves are not truly spherical—this being an advantage in some

cases for correcting aberrations. One of the greatest difficulties in the way of figuring, however, is that it is very difficult to determine what the departures from the spherical form are, and to always reproduce the same form. It is therefore of importance to be able to measure such curves, and it will be seen that the device just mentioned enables this to be done. If two apertures are used in the path of the light (fig. 5) it will be seen that the curvature is measured at a zone on the surface corresponding to the angle between the two converging rays; in order to measure the curvatures of various zones therefore, all that is necessary is to be able to vary this angle, and this may be done by employing the diaphragm of the form shown in fig. 6. This diaphragm consists of two plates, one having a rectangular slit in it, and the other one a slit of V shape, the second one sliding over the first. It is obvious therefore that as the second plate is moved over the

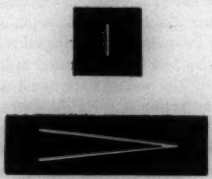


FIG. 6.

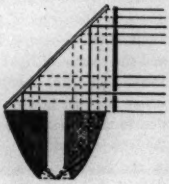


FIG. 7.

first, two apertures are produced which may be set at any distance apart, and consequently the angle between the rays may be varied to any convenient extent.

A difficulty still remains, however, that with many lenses a complete hemisphere is used, and it is consequently necessary to be able to measure with a cone of rays approaching 180°, this cannot well be done with a converging lens, but in this case the greater angle may be secured by using instead of an objective an internally reflecting paraboloid similar to that used for oblique illumination. Fig. 7 shows the arrangement in this case.

Of course, the figure of the surface may be obtained by simply using a narrow pencil and turning the surface so that light falls on different portions of it, but this is not as a rule so convenient, nor is it as accurate, as the method just described.

Determination of the Optical Properties of Small Lenses.

Although the method here described is particularly convenient for measuring curvatures, it is also capable of being used with greater convenience than any other for the measurement of the focal length and other optical properties of small lenses, and a few words may not be out of place on this subject.

Determination of Focal Length.

In determining the focal length of small lenses it must not be for-

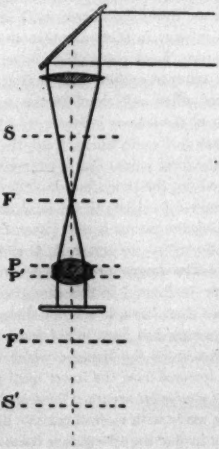


FIG. 8.

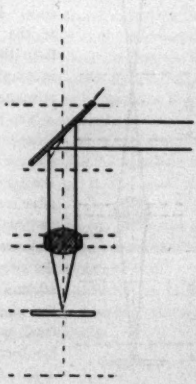


FIG. 9.

gotten that as a rule the thickness is far too large in comparison with the radii of curvature to be neglected, and consequently the whole of the measurements must be made as for thick lenses, we therefore require to know the positions of the principal and focal points.

In order to find the focal points a very simple device may be employed. The apparatus is set up precisely as before and focused on

the surface, the reading being noted, a plane silvered mirror is then placed below the lens and the microscope focused until the image formed by reflection in that mirror is sharp. It is clear that in that case the microscope is focused on the upper focal point of the lens or lens system, as the light coming from this point has been rendered parallel on passing through the lens and on return is converged to the same point. This is illustrated in fig. 8.

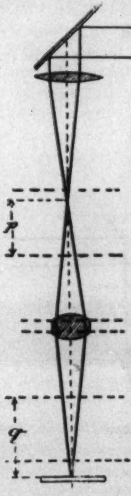


FIG. 10.

To obtain the second focal point the lens may be turned over, but it is more convenient to simply remove the objective and raise or lower the mirror until an image is seen. It is clear in this case that the mirror is at the lower focal point (fig. 9) as the light from the microscope tube is already parallel and is returned after reflection at the mirror and refraction at the lens as before.

The back foci or distances from the lens surfaces to the focal points can of course be directly determined in this way, but in order to obtain the equivalent focal length the simplest device is after setting the mirror to the lower focal plane as just described, to lower it a small known distance. The image produced by reflection at the mirror is focused in this case also, as in fig. 10, and we then have, if p is the distance which the microscope has been raised from the upper focal point, and q the distance which the mirror has been lowered from the lower focal point, $f = \sqrt{pq}$ Of course for accuracy these measurements should be made with monochromatic light. The procedure in the case of concave lenses is almost identical, but a concave mirror may be conveniently employed.

Much might be said about the testing of the other optical properties of lenses, their aberrations, &c., but it must suffice to say that it is possible by this method to make nearly every test necessary, and that the refractive index of the glass can be determined from a knowledge of the curvatures and focal length with a very fair degree of accuracy. It is probable even that the dispersion of the glass can be determined

with sufficient accuracy to identify it. Mention should, however, be made of its adaptability for accurately determining the centering of a lens system.

The ordinary test for centering is by Wollaston's method, *i.e.*, of seeing whether the reflected images can all be brought into line. One of the difficulties of this method is that the light transmitted through the lens is disproportionately brilliant and is apt to mask some of the fainter images. In this case as no light is actually transmitted the reflections from all the surfaces are seen with almost equal ease, and a considerable amount of accuracy can be imparted to the test by seeing whether the images from the various surfaces come exactly in the centre of the microscope field.

Another adaptation of this device is also to be found in testing the refractive index of glass by what is usually known as the microscope method. This method consists of focusing a microscope first on an object and then finding the amount that it is displaced by the interposition of a plate of the glass or other substance to be tested. If the plate, however, is very thin the method is not susceptible of much accuracy; but it can be greatly improved in this case, as by focusing the microscope a number of successive images can be obtained by internal reflection in the glass, and consequently the thickness of the plate is apparently magnified many times.

The author is at present engaged in designing a simple focometer on the principles described above, by which the curvatures or refractions of any reflecting or refracting systems can be easily determined.

It may not be out of place to add that the simple addition of the unsilvered mirror to the universal optical bench which I recently described, makes it suitable for curvature measurements.

Conclusion.

In conclusion it may be well to point out a few of the purposes for which such a method of curvature measurement is of value. The chief of these is undoubtedly in the case of microscope lenses, and I venture to think that it will be possible by this means to greatly increase the facility of experimenting with new forms of lenses and the standardisation of forms.

Another purpose for which it should be of value is the determination of corneal astigmatism, and more particularly of conical cornea, the latter of which cannot be easily measured by present methods.

The measurement of the curvature and refraction of the crystalline lens over different zones should also be easy by this means.

It will be noticed that I have said that the curves and qualities of glass used in any microscope lens may be determined by this method, and I am not sure that microscope makers will welcome a process which should enable others to find out the construction of their lenses. I must candidly confess, however, that it was precisely with that object that I devised this method, as I found it so difficult to obtain the particulars of actual lenses. In defence of this procedure I may say that I think that a more general knowledge of optical principles in the Trade, is of vastly greater importance than can be the possession of secrets relating to lens construction.

Unless English Opticians are educated as fully as possible in all the details of their work, and every facility is given them for acquiring information, it is to be feared that the superiority of Continental optical work will be even more marked in the future. Fortunately, however, the last few years has seen a considerable awakening in this respect, as witnessed by the examination scheme of the Spectacle Makers Company and the formation of this Society, and it is to be hoped that trade prejudices will soon disappear in the united effort to make the optical work of this country equal and surpass that of any other. I trust, therefore, that I shall be held excused for endeavouring to gain all possible information for the benefit of those who come under my instruction.

Finally, I must not omit to thank my assistant, Mr. G. Marinier, for arranging the experiments you have seen this evening.

ON SPECTACLE-FRAME FITTING, AND FACE MEASUREMENT.

By Mr. W. A. Dixey, *Member*.

Read before the Optical Society on December 13th, 1900.

IN coming before you to-night to read a paper on frame fitting, I feel that some excuse is due for the simplicity of my subject. But although the questions and conditions that are involved in the subject of frame fitting are not directly connected with the science of optics, they have a certain indirect connection; and I think I may at any rate assert that they are of great interest and importance to that large percentage of practical Opticians who have to do with spectacles.

I say that this subject is an interesting one: we must all of us have ideas about frame fitting. Take the most ignorant pedlar of spectacles in the country; he will at least aim at the best fit his means allow; while the man who is skilful and careful in his work will spare no trouble, but will devote all his energies to securing a good fit; for such a one will have learnt to recognise that there are few pleasures keener than the satisfaction which comes of a bit of work (however trivial) entirely well done.

But frame fitting is not merely an interesting subject, it is an important one. Hours may be spent and much thought devoted to the diagnosis and correction of a pair of defective eyes; and all the labour may be thrown away, and all the thought wasted, if the spectacle frame does not fit. An eighth of an inch one way or the other, the difference of ten degrees in the set of a side or a placquet, may make all the difference between success and failure. I wish this were more generally recognised. I often think that some people attach more importance to the fit of a coat than to the fit of their spectacles. At the worst a badly fitting coat fulfils its function of giving warmth and protection; it only looks bad. But a pair of

badly fitting spectacles not only looks bad, it is injurious to the sight, and may even affect the health. May we not then confidently assert that the subject of frame fitting and face measurement is one of importance ?

Now I am going to lay it down as axiomatic that the only way to get a perfect fit with a spectacle frame is to measure the face, and make the frame from the measurements. Much may be said in favour of a reach-me-down coat, but if you want a really correct fit, you must get your coat made to measure. So it is with a spectacle frame. If you will consent to follow me in this enquiry into the conditions that are necessary to a well fitting frame, you will without doubt admit that the possible variations are altogether too numerous to admit of a stock so large as to meet every case. But if I ask you to accept this, I want you to understand that there, for to-night, my dogma ends. In describing to you my method of face-measurement, I would represent it (I hope with becoming diffidence) as one merely of several possible means for reaching the desired end. In my case my present method is the result of a gradual evolution. Twenty years ago I began at the very beginning. We used to have a certain number of ready made frames in stock ; from them we picked out a few that looked about what was required ; one or two were put on the face, and one selected which seemed about right. We used even in those days, not infrequently, to fit a customer with a ready glazed frame, in which case the selection was made from a necessarily smaller number. At the most, if no fit was effected, and a frame had to be made, we were content with giving the workman the centres, and such indefinite directions as a reading bridge, wide or narrow crank, well bowed sides and so on.

It would be interesting did time allow, and my recollection suffice, to follow the gradual evolution of my present method during the twenty years I have been engaged in frame fitting. I will content myself with saying that every year has brought new methods and modifications ; I have adopted many appliances, and discarded almost as many ; I am still adopting and discarding—it is because I am conscious of this that I speak of my diffidence—I cannot even now regard my methods as final ; but at least I have reached this point ; that I can—simply and expeditiously—from a few measurements easily taken, convey to my workmen in some eight or ten figures the dimensions of a frame which will fit the face I have measured, provided only that I have done my part carefully and with intelligence.

Moreover, not only do I use this method with satisfaction to myself, but, and this is saying a great deal more for it, I have induced the gentlemen who assist me to use it, and I think modesty will allow me to assert that in their case the results are eminently satisfactory.

I now propose to examine in detail those measurements of the face that are necessary to the production of a well-fitting spectacle frame.

We will begin with the interpupillary distance, or, as it is commonly called, the centres. The first thing to note is that it is not convenient to measure from centre to centre of the eyes; if you try to do so, you have to guess the centre of each pupil, and a small error is most probable. A better point to take is the edge of the iris. If you work right-handed, measure from the nasal edge of your customer's right eye to the temporal edge of his left. These edges are better than the other two, because at these points the eyeball presents a surface more nearly normal to your line of sight. Subject to one little correction, which I will explain later, these points give you the exact distance between the pupil centres, except in the rare case of the diameter of the two irides being of different size. In such a case you may get absolute accuracy by taking two measurements, first at the near side edges, then at the off side, adding the two results together, and dividing by two. The other correction to which I have alluded is more important, and refers to the error due to parallax. You may avoid it by measuring your customer's right eye with your left, and his left eye with your right, though this method is open to obvious objections, and I think it best to take both measurements with one eye, and allow for the error in your reading. The error is not great if you are careful in your manipulation. Allowing two feet for a working distance, a pupil distance of two and a half inches, and the distance of the rule from the eye a quarter-inch, the error due to parallax works out at about one-fortieth of an inch; so that if you are a bit generous in your reading, it will nearly enough meet the case. At the same time, this error should always be kept in mind, as there are cases where, from one cause or another, as you can easily imagine for yourselves, a larger allowance has to be made.

Having carefully measured the interpupillary distance you are in a position to write down the first figure of your frame measurement—the desired centres of the frame. This will not always be the same as the pupil distance; for a variety of reasons (for which I refer you to my recent paper on "The Centring of Spectacle Lenses"), it may be desirable to make the spectacle centres wider or narrower than the

pupil distance, *e.g.*, the allowance for the convergence of the visual lines in reading is generally best made in the frames; though, of course, the frames may be made to the correct pupil distance, and the allowance made by decentering the lenses. Sometimes the construction of a face makes a divergence from the pupil distance desirable, as in the case of a thick nose in conjunction with eyes near together, when the frame may be made with wider centres and the error neutralised by a corresponding inward decentration of the lenses. So that it is well in making your notes during the process of face measurement to make some mark by which you can distinguish between the actual pupil distance and the desired centres for the frame. My own habit is to put a circle round the pupil distance; in fact, I use this circle round a figure as a symbol of a direct measurement, and find it very useful on other occasions as well.

Having written down the centres of your frame, the next dimension to consider is the width of the front. I know of no better method of arriving at this measurement than by the use of some such simple instrument as the one I have here. This consists of a spectacle frame made, you will notice, with ordinary sides, joints, and eyes, which last are glazed with flat glasses. I emphasise the fact of these parts being of an ordinary kind, because I consider that essential to a good result. It is also furnished with a mechanical bridge, of which I will speak later, and, for the purpose of front measurement, with an arrangement for altering the width apart of the joints (or sides). The method of using the instrument is as follows:—Practice enables you to judge with approximate accuracy the desired width. Set the sides accordingly and put the instrument on the face. If correct, good. If not, a single alteration generally suffices. There is a scale inside the straight bar, so that one need not delay operations by writing down the width immediately. Moreover, you must consider the width of your front, in connection with the curve (or bow) and character of the sides; and here again there is occasion for discretion; but the measurement you have taken with this instrument will in every case serve as a basis. I always work with the sides, which are 5 inch ones, bowed $\frac{3}{8}$ of an inch. Obviously, if I bow the sides of my frame a $\frac{1}{4}$ inch, I can have my front $\frac{1}{4}$ inch narrower, and *vice versa*. It is in this adjustment of sides and front that the discretion of the frame fitter is most exercised; and although nothing but the commonest of common sense is required, the success of the frame depends very largely upon that discretion. Thus a square head will

require a full measure for the front, and a slight bow for the sides; a round bullet head will take a deep bow, and a correspondingly narrow front. The maximum allowance for the front will be given by the instrument, as it is not wise to reduce the bow beyond $\frac{3}{8}$ inch; the minimum is fixed by the width of the centres and the size of the eyes; so that the narrowest front must at least measure the centres *plus* the major axis of the eye, and in this case turn-up joints must be fitted; with ordinary joints $\frac{1}{2}$ an inch should be added.

For an average effect a good general rule is to make the front $\frac{1}{2}$ short of two inches more than the centres, *i.e.*, $2\frac{3}{8}$-inch centres, $4\frac{1}{4}$ front; $2\frac{1}{2}$ centres, $4\frac{3}{8}$ front; and so on. Cosmetic effect should be studied in this connection, but it is impossible to lay down rules; tastes differ, and ideas are bound to vary as to the most beautiful type of spectacles. You will even find some people so blind to the beauty of spectacles as to condemn all alike. Enough that it is in these relations of eyes to front and front to facial contour, that the cosmetic effect of spectacles mainly lies.

Having correctly set the instrument to the proper width, we must proceed to the adjustment of the bridge—a very important item in the constituents of the frame. To define the bridge three dimensions are necessary; height, projection, and spread. The instrument is already on your customer's face, and you proceed to adjust the mechanical bridge, first for height, and then for projection. The height of the bridge regulates the position of the eyes, and the use to which the spectacles are to be put must be considered. Thus for general outdoor use the bridge must be lowered until, the eyes looking straight forward, the visual lines pass through the centres, or perhaps a little above the centres of the spectacle eyes; while for a reading frame the bridge should be raised till the eyes assume a suitable position for the downward direction of the sight in reading. Having fixed the height, proceed with the projection; the bridge must be adjusted forwards or backwards till the glasses assume their proper position, as near as possible to the eyes, but clear of the lashes. In making this adjustment direct your customer to turn sideways, and do not forget to allow for the curve, convex or concave, of the surface of the lens which will be next the face. Having completed this adjustment, after noting the position of the sides, of which more anon, you may take off the instrument, and lay it aside; subsequently you will measure off the two dimensions of the bridge with the spectacle rule. In writing down these two measurements, we take as zero positions

the horizontal axis of the frame, *i.e.*, the level of the crack of the joints; and for projection, the plane of the back edge of the eye wire. Dimensions below the first or inside the other may be written with a negative sign.

A third bridge measurement remains to be taken, and that is the curve or spread. This is of more importance than some are apt to think. Most people have a bony swelling towards the top of the nose, and if the bridge is so curved that it lies closely upon the eyeward slopes (so to speak) of this bony excrescence, it serves largely to keep up the spectacles in their proper position, and to prevent them from slipping down the nose. To take this measurement I use this spread-measure, a plain piece of boxwood or vulcanite with six graduated curves cut out of it, which, as a general rule, give sufficient variety, though if a nicer gradation be required half numbers may be used. A complement to the spread-measure is a bridge block, a valuable aid to the workman, over which he bends his bridge wire before it is soldered on to the eyes and tempered. In connection with the spread the character of the bridge may be considered, *i.e.*, whether crank, arch, or the so-called sweeping W. Why this bridge is called sweeping I don't know, and I think we might well drop the adjective and call it simply a W bridge; the more so, as this is the type of bridge which is best in nineteen cases out of twenty; mainly for the reason that with it you can always regulate (1) the rake so as to get it at an angle of about 45° to the sides, and (2) the depth which should be about $\frac{3}{8}$ of an inch. These two dimensions of rake and depth may be taken as standards, not to be deviated from unless you specify otherwise.

This completes our measurements for the bridge, and we now pass to a consideration of the eyes. There are two qualities which we must specify, shape and size. The shapes which I find most useful are round-oval, oval and half-oval. Oval, I suppose for cosmetic reasons, is the most generally accepted shape. You may vary your ordinary oval if you like, by having a deep oval or a shallow oval. Round-oval is a useful shape where large scope is required, *e.g.*, in spectacles which are worn both out-of-doors and for reading, etc., as well; spectacles for shooting, billiard playing, and so on. It is also a good shape for children's spectacles. Half-oval is a practical shape for presbyopes, as it enables the sight to be directed over the lenses, when a distant object is looked at. So much for shapes. Each shape must have a certain number of sizes, and you will see at once that

this question of size is an important one in connection with our subject of frame fitting, as it affects the width of the front.

The controlling dimension of the eye is the horizontal or major axis. Whatever system of sizes you use, it is incumbent, if you are to be a good frame fitter, that you should carry in your head this dimension for each size. My own practice has been to arrange all sizes with reference to this consideration. I number my eyes from one to four. Whatever the shape, each number has the same major axis. No. 1 has a major axis of $1\frac{1}{4}$ in., No. 2 of $1\frac{3}{8}$ in., and so on. So that no matter what the shape, I always know at once what proportion of the spectacle front the eye will occupy. Four numbers seem enough, but here again, if nicer gradations are required half numbers may be used.

Perhaps this is the place to allude to a mistake that a beginner may easily make; that of leaving insufficient space for the nose between the eyes. A thick nose will often require $1\frac{1}{8}$ or $1\frac{1}{4}$ inches of interval. Centres *minus* eye gives the space. So that with centres $2\frac{1}{4}$ and with such a nose to deal with you cannot prescribe No. 3 eyes.

Centres, front, bridge and eyes have now been dealt with, and there remains only the consideration of the sides. In single sides the length should be given. They should go about an inch beyond the ear. I work, as I told you, with a 5-inch side on my measuring instrument. Any desired addition to or deduction from this length can be gauged by eye, if the position of the side is noted when you have your customer side-face. For turnpin sides the sides of the measuring instrument may be touched with a yellow pencil, and the length of a curl-side, or rigid hook-side, may be gauged in the same way, or by the bent side with scale attachment with which you are doubtless familiar. In using this last, the mechanical frame should be on the face and the measure made to the crack of the joint. A deduction of $\frac{1}{8}$ to $\frac{3}{8}$ inches must be made from the reading so taken, proportionate to the pliancy of the side—I have already alluded to the bow of the side; there seems nothing more to add, except that in writing down the bow it is convenient to use brackets as a symbol, thus $(\frac{1}{8})$. The last point for consideration is the angle at which the sides are set to the front. As a rule the best angle for spectacles for general use is a right angle, and that angle may be assumed unless another is specified. For reading, writing, and generally for close work, the best inclination for the sides is at an angle of from 70° to 80° with the front. The position to aim at is that the front may be as nearly as possible

normal to the average direction of the visual lines. Exact measurement is unnecessary. But before experience has taught accuracy, the measuring instrument may be tilted till the desired position of the front is obtained, and the angle which the sides then make with the line from joint to ear may be noted or, if necessary, measured.

This concludes the measurements that are necessary in an ordinary case for the specification of a properly fitting spectacle frame. The process is so simple that I am myself rather astonished at the length to which the description of it has run. I propose now to demonstrate to you its simplicity and the expedition with which these measurements are made. The complete series of measurements can easily be taken in 1½ minutes; and to a practised man another minute is ample to write out the working specification for the frame.

It was originally my intention to give hints as to how to deal with exceptional cases, but I think it may be more interesting for you to suggest difficulties and to let me explain my method of meeting them by way of reply. Another interesting subject of study which I will not deal with at present is face measurement with reference to the fitting of eyeglasses. Perhaps on some future occasion, if I have not exhausted your patience, you will allow me a few further observations on that subject.

ON TELESCOPES AND FIELD GLASSES.

Paper by Dr. D. Kaempfer, Brunswick.

In the history of natural philosophy and science the invention of the telescope in the beginning of the 17th century was of the greatest importance. It must, however, be stated that the influence on the progress of science did not prove to be so great at first, although Galilei succeeded in discovering the satellites of the planet Jupiter by it. The renowned astronomer Hevelius even in 1650 could still deny with certain right the efficiency of the telescope in comparison with observations by sharp-sighted eyes. The reason why the telescope could not help failing was that no means were extant in those times to diminish the chromatic and spherical aberrations both in the objectives and in the eye-pieces; and no less an authority than Sir Isaac Newton, who at first taught the world by his wonderful experiments how to divide the white sunlight into its seven coloured parts, prevented makers of telescopes from trying to counteract these deviations, because he declared it to be impossible.

It was not until John Dollond in the year 1757, in London, combined in spite of this great authority, crown and flint glass to form the achromatic objectives, that this great progress came forth. Since that time a continual improvement of all the systems of telescopes, both of the Galilean and the Kepler types, with astronomical eyepieces and terrestrial ones has been made. Mathematical investigations and new methods of melting good optical homogeneous and suitable glasses, practical accomplishments of the art of polishing and centering the lenses, in order to execute the design in the most perfect manner cumulated with one another to bring this wonderful instrument—the telescope—to the highest pitch of perfection. Names like Lippershey, Galilei, Kepler, Dollond, Herschel, Lord Rosse, Fraunhofer, etc., will never be forgotten if we are to review the development of this branch of optics. From a historical point of view we are bound to remember these names even if we are to only give a short sketch of small telescopes for practical use, Galilean and prismatic binoculars, which are the subject of my lecture.

The oldest type of telescopes for free use in the hand is the Galilean opera-glass, constructed as binocular glasses at first by Frederick Voigtländer in Vienna, in the year 1811. They are composed of an achromatic double or triple objective with the ratio of aperture to length of focus of 1 : 3 up to 1 : 5, and a negative (single, double or triple) eyepiece, placed in its normal position at a distance equal to the difference of the focal lengths of the objective and eyepiece. The eyepiece being set in the course of the pencils of light piercing the objective, the images are not really produced, but are upright. Let us now contemplate only in the outlines the course of light in those glasses.

O is the objective, *P* the eyepiece, *E* the human eye, then the pencil of light piercing through *O* from the left side is converged by *O*, meets *P*, where its convergency is lessened, coming thus into the eye *E*. If we follow *vice versa* the rays from the pupil of the eye through the eyepiece *P* and the objective *O*, we are enabled to find the field of view

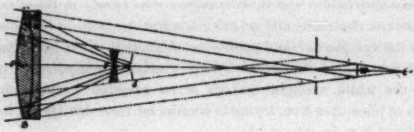


FIG. 1.

enclosed between the lines *AC* and *BC*; those lines cutting each other in *C* give the angle of the field *W*. This shows evidently, that the field of view depends upon the size of the object-glasses, and is restrained by the impossibility to make them larger than $2\frac{1}{4}$ ins. approximately, the distance of the eyes being only $2\frac{1}{2}$ ins.

The Galilean glasses possess the advantage of being comparatively short, the distance of objective and eyepiece equalling the difference of the focal lengths of both. Furthermore, there are only a few lenses through which the light passes; therefore, absorption and false reflexion are reduced to a minimum. The image, therefore, is most brilliant, not covered by ghosts or weakened by absorption in thick lenses.

The illuminating power of the Galilean binocular cannot be excelled, it equals very nearly that of seeing with unaided eye, *i.e.*, the utmost to be attained, for an optical system is never able to increase the natural light. I have brought with me some specimens made by

Voigtländer and Sohn, glasses in all forms and mounts, from the magnifying power of $2\frac{1}{2}$ up to 7, in metal and aluminium, with triple achromatic objectives and eyepieces. You will be able to examine them afterwards. I should like to draw your attention to some special glasses, with six lenses, whose bars are absolutely united with the bodies, both in metal and in magnalium, the new and wonderful alloy of aluminium and magnesium, on which I shall make some remarks after having finished this subject. This mechanical design makes the glasses extraordinarily steady and prevents them from coming out of adjustment.

Here is a model of the German navy night glass, the German artillery glass, etc.; the artillery glass has the same optical outfit in a more compact mount.

If you hold these glasses up to the light, the eye being in some distance from the eyepiece, you will see an illuminated round circle of

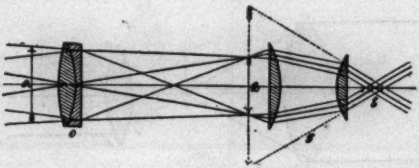


FIG. 2.

more than $\frac{1}{3}$ of an inch in diameter; this circle is therefore larger than the pupil of the human eye, which altering according to the changing light, can become as much as $\frac{1}{3}$ inch in darkness. The pupil of the human eye determines the amount of light which reaches the retina.

Though the illuminating power is the greatest possible, the Galilean glasses possess disadvantages which makes them unsuitable for use in some cases. Above all, the magnifying power is comparatively low, from two to seven or eight diameters, as higher powers make the glasses very large and inconvenient to hold, and diminish the field of view enormously.

It is quite natural that Kepler's astronomical telescope, consisting of two positive systems of lenses, seemed to offer greater advantages in this direction, the eyepieces possessing a field of view of 40°. But

the images were inverted and upright images are required for terrestrial use. A rough sketch will show us this.

O is the achromatic objective, P the astronomical eyepiece; then an image of the object is really produced in B. You see from the course of rays that the image in B is upside down, and that the eyepiece does not erect it. Another essential difference between the astronomical and Galilean telescopes is that the image of the objective obtained by the eyepiece is produced in this case outside the telescope on the right side, as you can convince yourself if you hold such a telescope against the light. In the Galilean type, however, this illuminated circle, the so-called emerging pupil of the light, is seen between the objective and eyepiece. This circle, the emerging pupil or Ramsden's circle, has a great importance in the theory of telescopes of any kind and it may consequently be worth while to explain it in connection with the magnifying power.

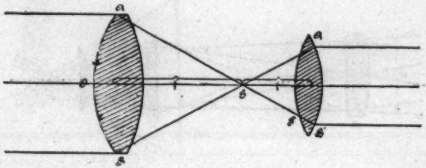


FIG. 3.

Let us represent in our mind the telescope in its most simple shape. Fig. 3 shows the telescopic system in its normal position, objective O and eyepiece P are simple bi-convex lenses, their distance is the sum of the focal lengths f and f^1 the second focus of O falling together with the first focus of P in the point G.

Parallel light to the axis is converged in G the focus of O; coming from G as the focus of P, the refractive power of P will make it parallel to the axis. This parallel pencil forms the Ramsden's circle, the emerging pupil, and as we are enabled to see here, it is the image of the objective O, formed by the eyepiece P. It can easily be seen, if we look on the eye-glass at a short distance, holding the telescope against direct light or an illuminated white sheet of paper. The Ramsden's circle gives us all that is necessary to judge the illuminat-

ing power of a telescope, the larger its diameter the greater is the light and *vice versa*.

But it will tell us more than that if we look at the sketch, fig. 4, in order to obtain a geometrical view of the magnifying power.

The object glass O produces a real image $A'B'$ of the distant object AB, which is smaller (inverted), and is situated at the distance of its focal length f. The eye seeing A' B' through the eyepiece P will bring it apparently into the position CD, the distance between P and $A'B'$ being f', the focal length of B. The angle, under which the object AB is seen is α, the angle under which the image CD is seen is β; the ratio β/α is the magnifying power. Contemplating the triangles $OB\,G'$ and $PB\,G'$ we conclude, supposing the tangents of small angles equal the angles themselves, that the magnifying power β/α equals the ratio f/f' of the focal lengths of the objective and the eyepiece. The

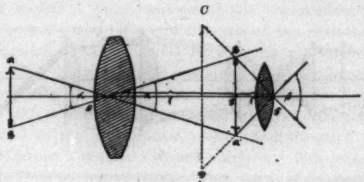


FIG. 4.

angle δ is called the apparent field of view of the eyepiece, hence the real field of view equals the ratio $:\beta$ divided by the magnifying power. If we look at fig. 8 again we are allowed to conclude that the ratio f/f' equals the ratio

$$\frac{\text{diameter of objective}}{\text{diameter of Ramsden's circle}}$$

the triangles AGB and $A'GB'$ being similar to each other.

We have, therefore, won three very important theorems by which to judge the efficiency of telescopes. Firstly, the magnifying power equals the ratio of the focal lengths of objective and eyepieces. Secondly, the same equals the ratio of diameters of objective and Ramsden's circle. Both can be easily measured, and from these measurements the magnifying power can be derived. Accurate instruments are designed for this purpose, for instance, Ramsden's

dynometer, but we have not time to refer to them now. In many cases it is sufficient to apply a mechanical measure. Thirdly, the real field of view equals

the ratio: $\frac{\text{apparent field of view of the eyepiece.}}{\text{magnifying power.}}$

We may add that the Ramsden's circle also gives the illuminating power, so that we are enabled to judge all the geometrical properties of a telescope.

Naturally our theorem of the ratio of the diameters of objective and Ramsden's circle is only available, if the objective is not stopped down artificially, in order to improve the definition. We can see ourselves if this has been done by looking at some distance through the objective of the telescope; if the whole aperture is illuminated, the telescope is not stopped down.

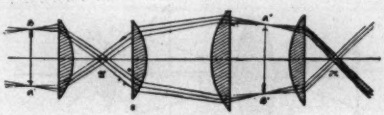


FIG. 5.

The astronomical telescope gives the picture inverted which peculiarity excludes it from practical use for terrestrial purposes. In order to make the image upright we are obliged to bring between objective and eyepiece a reversing system, as shown in fig. 5. $B'A'$ is the reversed picture of an object, designed by an objective; then the pencils of light coming from A' and B' piercing the lens 1 cross the axis in U, going through 2 and 3, they form in $A''B''$ the upright image, which is observed by the eyeglass as a magnifier. It can be easily shown that the lens 3 determines the field of view, as a collective lens.

You see here some of the standard forms of terrestrial telescopes, now in use, manufactured by Messrs. Voigtländer and Sohn, for their English and American friends, as well as for the German navy, the German army preferring binoculars. One, with an aperture of $1\frac{3}{8}$ ins., magnifying power 18; the other with an aperture of $2\frac{3}{4}$ ins., power 26; they are the standard patterns of the German navy.

English gentlemen mostly prefer for military as well as for sporting purposes, deer-stalking, etc., draw telescopes, both in aluminium and in brass with the same optical outfit, as they are more portable.

The advantage of the terrestrial eyepiece is balanced by many disadvantages, chiefly the great length and deficient flatness of field. So it is nearly impossible to build up satisfactory binoculars of this design, being too long and heavy for practical use. The astronomical eyepiece in all these respects is by far superior; all the good efficiency being spoilt by the employment of the reversing system in the terrestrial telescope. But there is still another means to reverse the image in an astronomical telescope, that is Porro's combination of two equilateral and rectangular prisms. This useful construction has been invented by the Italian mathematician and engineer, Porro, as early as in 1853, and it was not until in 1869 that earnest trials were made to introduce it into practice.

In these models I have represented the combination of Porro-prisms. The white wire represents the axis of the objective and of the parallel pencil of light piercing it; it meets perpendicularly the hypothenuse of the right angle equilateral prism, without suffering refraction or reflection at that surface. Then it hits the first side at an angle of 45°, thus total reflection must take place, the reflected ray going parallel to the hypothenuse meets under the same angle the second side, where it is again reflected totally and then emerges perpendicularly from the hypothenuse. This course of the ray is marked on the outside of the prism. The ray emerging from the first prism meets the other prism, whose refracting edge is set perpendicular to that of the first prism, perpendicularly on its hypothenuse, undergoes in the same way two total reflections on its catheti, whereupon it emerges from the second prism in a direction perpendicularly to its hypothenuse thus represented by the red wires.

A refractive effect is nowhere produced, only four reflections take place, the pencil of light coming from the objective emerges in the same direction, only displaced in a parallel line. The inverted image given by the objectives becomes upright by these four reflections, but where does it come from? To form the right idea of these phenomena we compare the effect of the first two reflections with a right-angle mirror. In such a mirror right and left side, or up and down, are always inverted, according to the position of the edge. If the edge is perpendicular on the horizon of the observer, then right and left are changed: if the edge is horizontal, top and bottom are changed. Con-

sequently a complete reversion of an image, right and left, and top and bottom, is only provided by two perpendicularly crossed right-angled mirrors or what signifies the same, by two right-angle equilateral totally reflecting prisms, crossing each other rectangularly.

You can convince yourself of this fact by experiments with such two prisms, as I can show you here. Take the one, hold it, the edge being perpendicular, on the ground; right and left are changed; hold it, the edge horizontal; top and bottom are changed. Both of them combined with parallel edges give no inversion at all, the two efforts paralysing each other, the inversion will not be realised till the two prisms are crossed and you see how the image is turned over if you move the one prism into the crossed position, looking constantly in the meanwhile through the other prism.

From our models it is evident that the direction of the pencil of rays is displaced. This can be used in binocular glasses for enlarging the distance between the objectives. This property has been used for obtaining a higher stereoscopical effect, similar to the telestereoscope invented by Helmholtz about 40 years ago. But the stereoscopical effect can also be produced and in smaller instruments to a greater extent by using higher magnifying power. But another property of this combination is of a by far greater practical use. It is that the Porro combination shortens the telescope a good deal, the course of the rays being composed of three tracks going beside each other, of which two can be subtracted from the length of the telescope, and of two tracks parallel to the hypothenuses and perpendicular to the axis, which possess no influence at all on the length of the instrument. These two principal advantages of the Porro combination over the terrestrial reversing system, that it does not spoil the wonderful efficiency of the astronomical eyepiece and shortens the length of the telescope so much, are of the highest importance for binocular glasses, for in this line shortness and compactness are of the greatest importance. Let me tell you some words about the historical development of these instruments in our firm. You will see here a monocular telescope with a combination of Porro prisms for reversing the image and an astronomical eyepiece. It was constructed in 1869 as a telescope for the Austrian cavalry, but was set aside afterwards on account of its deficient illuminating power. Later on it was discovered that this construction possessed the faculty to fill up a gap between the Galilean binocular glasses and the telescopes with ter-

restrial eyepieces only for use in the free hand. We designed and brought out prismatic binoculars with single adjustment for the eyes and with simultaneous adjustment for both eyes. The latter are almost invariably preferred.

You see here the ordinary patterns of prismatic binocular glasses, magnifying powers 3, 6, 8, 9, and 12 diameters; the optical effect is the best attainable, the Ramsden's circle being between 4, 2 and 1,8 mm., the illuminating power is quite sufficient for the use during the day, when the pupil of the human eye only possesses the same diameters. The image is sharply cut, achromatism and flatness of field are perfect. The apparent field of view lies between 36 and 42 degrees, the real field of view between 3, 5, and 10 degrees. You will overlook 105 yards in a distance of 1,000 yards by means of a binocular of six times, 61 yards with one of 12 times. Beyond 12 times it is not of a practical use to raise the power, though the task for the Optician is no more difficult than with 12 times. The objective is double achromatic, the prisms of the purest, brightest glass material, so that the loss by absorption can be nearly considered as imperceptible, the eyepiece is a so-called Ramsden one, the collective glass turning its plane surface to the objective, the eye-glass is double-achromatic.

There are two more samples of a special line of binocular-glasses, one with the magnification × 3 has an enormous field of view, overlooking 200 yards in a distance of 1,000 yards, although it is built up in a much reduced compass. The converging pupil being 4 mm., the luminosity is comparatively great, consequently the glasses are most useful in the theatre, when it is desired to overlook at one time the whole scene. The other glasses, magnifying × 4 possess the highest luminosity of all prismatic binoculars, the converging pupil having a diameter of 7 mm., they will naturally be applied with the greatest success at dawn, in weak light, etc.

I may be allowed to mention something about the optical and mechanical workmanship and portions. In the ordinary prismatic binocular glasses we do not only employ the simultaneous adjustment for both eyes by an ordinary propelling screw, but also use an appliance for one eye to compensate the frequent difference of efficiency of the two eyes. I have brought with me such a single eyepiece, to show the mechanical movement. Bodies, and nearly all other metal parts, are cast out of the firmest alloy of aluminium, formerly aluminium-copper, now aluminium-magnesium or magnalium, the

newest, lightest and steadiest of all these alloys. This cast body will show you how the prisms are set and fastened, etc.

I should like to point out that a good design only is not sufficient to build up a good instrument for the use by free hands, but that the best workmanship is indispensable for manufacturing these glasses, both in the optical and in the mechanical parts. Particularly the prismatic binoculars offer manifold difficulties in accomplishing them so steadily, that they are enabled to stand against any injury and keep up their adjustments. How Messrs. Voigtländer and Sohn have overcome this difficulty, these patterns will show, and the experience that dropping on the ground, knocking on the bodies, etc., hardly ever spoils them. Prisms must be of the highest performance, as well as the objectives and eyepieces, the least want of perfection will make an adjustment impossible. A similar theorem is available for Galilean glasses and hand-telescopes, although deficiency in the workmanship with those glasses will not be of so great influence on the adjustment itself. But the effect is spoiled in this case as well as in the case of the prismatic binocular, if the workmanship and finish are neglected. Perfect centering of the single tubes and of the lenses in them, parallelising of the binoculars, absolutely spherical and highly polished surfaces are necessary in every case, so that a great deal of labour, pains and cleverness always remain for the conscientious manufacturer.

I may be allowed to conclude my explanations with a summary on the choice of glasses for the use in the hand. Three cases are to be considered. If the highest luminosity is required, that which enables us to make full use of the natural property of the human pupil when very widely enlarged in dim or weak light, Galilean opera or field-glasses are to be employed, for instance, in the theatre, if one will not only see the illuminated scene but also the dark parts, or on board of a ship during the night to find the marks on sea or ships, etc.

If on the contrary the highest magnifying power is desired, a hand telescope, magnifying fifteen to thirty-six diameters, and luminosity does not signify much, only terrestrial telescopes are to be chosen with an emerging pencil of 2 mm. as an average. It will be sufficient in day-time, for then the human pupil will have a similar diameter. These telescopes therefore will be of the greatest use on board a ship at day time, and when deer-stalking, hunting, etc.

If, however, a medium performance in both respects, both in luminosity and in power are asked for, prismatic binocular glasses will

come into question, standing in the most important qualities between the Galilean and terrestrial types of telescopes. They are the right instruments for universal use, although naturally they cannot give the utmost advantages in every direction.

In order not to omit anything belonging to the subject of my lecture, I should like to bring before you another interesting instrument, which is also used by hand. It is the aiming or sighting telescope. This is an extraordinarily short terrestrial telescope, serving instead of the mechanical sight on a rifle but avoiding its great faults. Taking aim signifies that four points, the object, the two parts of the sight and the eye, are to be brought into one straight line. But if you accommodate your eye on the object, you can never see the sight sharply and *vice versa*, hence the faults in aiming. In the sighting telescope the image of the object falls together with the cross wire of the telescope, consequently no fault of accommodation can occur, the aiming is absolute. Naturally the telescope must be fixed and adjusted in a practical and reasonable way, as Messrs. Holland and Holland and other firms do here in London. In Germany all the great sportsmen possess such rifle telescopes, following the example of the Emperor. Perhaps it may be of interest to you to see this rifle with the telescope on it, and have the details explained afterwards. It is naturally of very great assistance for sharp-shooting with the rifle. For the different distances the mounting of the telescope is managed in a way to allow the cross wire to be elevated according to the distances. For this purpose it is shot at a target and the corresponding heights of elevation marked.

MAGNALIUM.

By Dr. D. Kaempfer, Brunswick.

Read before The Optical Society on February 5th, 1901.

IN my paper on "Telescopes and Field Glasses" I have mentioned a new metal called magnalium. It is an alloy of aluminium and magnesium, having properties so remarkable and so useful that I feel myself bound to give you an account of this invention.

As you will know very well the introduction of aluminium into the great industry has proved to be a serious disappointment. As a light metal, however, for special purposes where firmness and rigidity are not required it is still very valuable. You will remember keys made of aluminium fifteen years ago which broke the first time they were used, so that we may say it is not a metal for universal use. After the manufacturers had overcome the great difficulty of making it by the adoption of an electro-metallurgical method difficulties of another character arose for them, viz., how to sell it. The extremely light metal aluminium is not firm and proved most difficult to work. It blunted the cutting edges of files, etc. In this respect it is similar to pure copper, but much worse.

As copper is alloyed with tin to give the useful hard bronze and with zinc to give brass, which is tough and firm, and can be turned and wrought in the easiest manner by all tools without any oil, it seemed useful to try to melt aluminium together with other metals. Metallurgists selected for this purpose: copper, silver, tin, and zinc. With these they succeeded in getting alloys of better qualities than pure aluminium possessed. The specific gravity, however, was raised to 3·5, so the chief advantage of aluminium was much reduced without attaining the purpose. These alloys were very rough in breaking, with many small holes and not nearly firm enough for use in machinery and engineering. Their properties were very similar to cast zinc. The chief defects are that tools cannot be used without oiling, screws were weak and not cleanly cut, and it was impossible

to have tubes of these aluminium alloys arranged to slide in one another.

Now it seemed a good idea to mix, as we do in bronze and brass, similar metals with each other of similar specific weight, for instance, aluminum and magnesium. As early as 1866 the great chemist, Wöhler, at Göttingen, melted aluminium and magnesium in the proportion of equal equivalent weights 27·5 and 12. He obtained a very brittle alloy which could not be wrought by tools and which would not resist the atmosphere. It was the same case with all the other alloys he made, and he always used more magnesium than aluminium. All his successors employing similar ratios of the metals failed likewise.

For all that a young physicist, Dr. Ludwig Mach, was not deterred from studying the question systematically. He followed the analogy of bronze and brass precisely and stated one metal must be the principal one: copper in bronze and brass; and in the alloy to be made, aluminium, the other component tin, zinc, or magnesium only to be in a small quantity. By experiments he ascertained that 10 to 30 parts of magnesium added to 100 parts of aluminium produced a metal, called magnalium, which is not only firmer than brass, but can be worked and turned, etc., as easily as brass or bronze, its specific weight being under one-third that of brass. The specific weight of magnesium is 1·7, of aluminium 2·7, of magnalium 2·2 to 2·5.

Magnalium is as firm as wrought iron. The surface of a fracture is similar to that of steel. It can be turned, bored, drilled, milled, filed, ground, and polished easily. Its colour is an extremely pure white, as you will see for yourselves. It can be easily nickel-plated or gilt, and takes a good black. It is also important from a mechanical point of view that tubes of magnalium can slide in each other without becoming tight by the metal fretting. Screws made of magnalium are very strong and the threads pure and durable. Here are a few photographic lenses, the well known Collinears, made by Voigtländer and Sohn, mounted in magnalium. They show the advantage of this metal, lightness in weight, and firmness, fine screws, tubes in each other, and so on. Here are also prismatic field glasses, which are chiefly made of magnalium: Galilean glasses entirely mounted in magnalium. These instruments alone are all that are necessary for an expert to form a correct opinion. Magnalium is, moreover, extremely suitable for mounting lenses, as it is easy to bend sharp brims of the metal over them.

Dr. Mach found that by mixing a smaller quantity, as to 2 to 8 parts of magnesium with 100 parts of aluminium, a wonderful metal is obtained for drawing and stretching, consequently for the manufacture of tubes and plates. The melting point of all these alloys is approximately 700° Centigrade. As sometimes a higher melting point is required, Dr. Mach found that the addition of antimony raises it up to white-heat.

In conclusion it may be said that Dr. Mach has found magnesium to be a very fine and sensitive means of regulating the firmness, solidity, etc., of this alloy. Magnalium resists atmospheric influences; it does not oxidise at all. Fumes of ammonia and sulphuric acid do not damage it. Experiments in soldering have been made with good results, and it can now be soldered easily. According to the measurements of the Technical Institute at Charlottenburg, the breaking strain lies between 22 and 24 kg. per square mm. It is therefore stronger than cast iron and similar to cast steel, so that bearings and other parts of machinery can be made of it. Its use in future will therefore not be restrained to the manufacture of instruments, but will be extended in engineering, ship-building, and motor-cars, etc. A very good beginning in this line has already been made. Magnalium has been patented in nearly every country and is now being manufactured by the Magnalium Company, of Berlin. This company manufacture tubes, etc., make castings from patterns sent to them, and also sell the raw material with exact instructions how to cast, draw, roll, and solder it.

THE EDUCATION OF THE OPTICIAN.

By W. A. Dixey.

Presidential address to the Optical Society, March 28th, 1901.

IT is a privilege accorded to the President of this Society to address a few words upon a subject of his own choosing to the first meeting of the Society at which he presides. In trying to select a subject which would be of general interest, I have thought that I might venture to invite your attention while I put together a few ideas on the subject of the Education of the Optician. The subject is a large one, and I cannot hope to do more than deal with it in very sketchy fashion; but that there may be some order in the remarks which I have to offer, we will begin by constructing a framework on which to hang them. We will first then consider what we mean by an Optician, and what an Optician should know; we will then examine what part of the knowledge and capabilities of the Optician can be instilled by education; and lastly we will enquire what facilities are offered by different schools and institutions for the acquisition of such knowledge.

Definition of an Optician.

Our first task, to define an Optician for the purposes of this paper, is not an easy one. We may begin by dividing him into three classes, the working Optician, the trading Optician, and the academic Optician. If we exclude from our consideration the first and the third, we are left with the trading Optician. But he, unfortunately, is not a simple entity. He may be retail or wholesale, master or assistant, his place of business may be a factory, a warehouse, a retail shop, or any combination of these. His work may be confined to one instrument, or to one class of instruments, or it may be distributed over the whole range of so-called optical instruments, in the large sense which includes thermometers, barometers, and such like. We cannot promote separate enquiries into all these possible ramifications; I think we

shall best deal with our subject, if we imagine a comprehensive Optician, who deals in everything and does everything that belongs to the optical trade. It will be easy to separate from such an one any branch of the subject that does not concern an individual case.

What then ought the Optician to be, and what to know?

Preliminary Education.

He should be educated up to a certain point in mathematics, in letters, and in languages. To his mathematical education I would put no limit other than his mental capacity and other opportunities may fix. It is true to say that the more mathematics he has the surer will be his grasp of nearly every quality of the optical instruments in which he deals. But we may take as a minimum the requirements of the Spectacle Makers Company; the standard is not a high one; a thorough knowledge of arithmetic, algebra to quadratic equations, and an elementary knowledge of geometry and plane trigonometry; without so much mathematics it is impossible for the Optician to read the books of his subject intelligently, nor can he carry on his work from day to day without being constantly confronted with questions which demand solution, but which are beyond the limit of his comprehension.

His literary education is, in my view, of secondary importance; but it should be carried to the point of enabling him to speak correctly, and write grammatically. The Optician in the course of his career has to get through a great deal of talking. He spends a considerable portion of his working hours in giving advice. His words, whether spoken or written, cannot but fail of their proper effect if they are not conveyed in correct form. It is the equal mind, the balanced judgment, induced by the study of letters, which prevent our talk degenerating into quackery; while a correct style will often, in the estimation of the hearer, elevate a platitude to the plane of studied wisdom.

Languages may be regarded as a branch of letters; and I want to lay it down as a counsel of perfection that the Optician should acquire a familiar knowledge of French and German; firstly, because he should keep himself informed of what is being done in his branch of science in those countries as well as in his own; secondly, because he will find it useful in his trade to be able to correspond directly with foreign manufacturers and customers; and, thirdly, because a young man must learn something, and as an Optician he will find modern languages useful in a variety of ways.

These three subjects, mathematics, letters, and languages, which I put in the order of their importance, are to be considered as the foundation upon which the Optician will build his technical knowledge; and we must now consider, neglecting for the moment the means of acquiring it, of what this technical knowledge consists.

What the Optician Should Know.

The Optician should know something about all the instruments in which he deals. He should know how they are made, where they are made, and who makes them. He should know how they are used, what they are used for, and who uses them. He should be able to discriminate between different makes of the same instrument, compare workmanship, efficiency and prices, and advise accordingly. He should know the different qualities of similar imstruments, which quality is better adapted to which kind of work, and advise accordingly. All this he should know, not only of the instruments themselves, but of the apparatus and accessories that belong to them. Let us enumerate some of the instruments in which he deals, and we shall be struck by the interesting variety of these demands. There is the microscope—you will see that each one is really only a heading,—the telescope, the field glass, the opera glass, the photographic camera, the optical lantern, the barometer, the thermometer, the compass, mathematical instruments, nautical instruments, surveying instruments, and a great variety of others which it is not necessary to recall; and in addition to these the Optician requires a more specialised knowledge of spectacles, and all that pertains to them. This, in general terms, is the necessary technical knowledge of the Optician.

The inference that I want you to draw from the variety of the technical subjects is the necessity of a sound fundamental education. If you have a thorough comprehension of the common phenomena of light, the laws which govern its reflection, refraction, and dispersion, you have in your grasp the principles of every optical instrument. The necessary technical knowledge, of which you make daily use, is most often an obvious deduction from the properties that are familiar to you. But if these fundamental properties are unknown or half known, you are on a very different footing. In a sense you may know your instrument, and its use; but you have learnt it from the outside; the labour is great; it differs for each instrument; and moreover that kind of knowledge will probably find you wanting, when anything is demanded of the instrument, which is the least out of the common.

Technical Knowledge.

So that we shall do well to build upon the foundation of mathematics, letters and languages a sound knowledge of the common properties of light and their application to optical instruments. With this equipment the Optician may be considered well prepared for the acquisition of that knowledge of his instruments which will be directly useful. For the acquisition of that knowledge he may still rely to a certain extent upon what is generally implied by the word education. Lectures on special instruments, and especially laboratory work at technical institutions, may teach him much. He can also get a good deal of knowledge by his own reading; but for the most part he must rely on his native wit, his energy and enterprise, and the opportunities he has of handling, studying and testing the instruments themselves, using throughout his investigations that intelligence which his preliminary studies have enabled him to apply.

The Value of Intercourse.

In this connection I would point to the valuable assistance which a society such as ours may render. It is a common-place of history that, in the life of a nation, intercourse, whether friendly or hostile, is a condition of progress. To be isolated is to stagnate. I conceive this as a wide-reaching truth; and I venture to suggest that the many and various opportunities for intercourse offered by this and other societies may be so used as to become a valuable factor in the education of the Optician.

Practical Application of Knowledge.

It would perhaps be interesting, by taking a specific instance, to trace the origin of what knowledge an Optician makes use of in an ordinary every day transaction. A customer wants a night glass for use on board his yacht. The Optician will discriminate between the different classes of binoculars, and will recommend the Galileo system of lenses on account of its relative luminosity. That advice will be drawn from the intelligent application of his studies to his knowledge of instruments. The glass should have six or twelve lenses; his studies enable him to advise. He must determine the magnifying power. Studies here are only a partial guide; his advice will also depend on the use to which the glass is to be put. He notices that his customer has an exceptionally wide pupil distance. His knowledge of optics and of the

construction of fieldglasses suggests that advantage should be taken of this condition. The customer enquires as to price. Studies are no use here; he must rely on his trade knowledge. Having secured the order he has to get the glass made. He should know in what workshops this can be done, and should discriminate between them. That is trade experience. He must specify the form, material, dimensions and optical qualities of the glass, either in consultation with the workmen, or with a knowledge of the capabilities of the workshop. If, for the sake of price or any other cause, he sends his order to France or Germany, he should be able to write his specification in the language of the country. You will see that the knowledge that enables him to do all this has mostly come by education; although, without what I have called trade knowledge, he could not in my opinion take the order and carry it out properly.

Or, let us take an instance from the work of an Optician trading in a country town. In his neighbourhood is a large brewery or some factory where the microscope is used. His native wit will prompt him to discover the uses to which the instrument is put. His optical studies will teach him the best and most economical form of instrument for the purpose, his applied intelligence will ascertain the best conditions of lenses and light that the instrument should assume, his trade experience will tell him the best maker, or it may be the best makers, for he may get stand of one, objectives of another, and accessories of a third; and if the orders do not come to him, it will not be his fault, or he may be spurred to fresh efforts by the knowledge that they have gone to some one who has done these things better than he.

I hope I have now said enough to convey to you my conception of what an Optician should know, and what part of his knowledge he may acquire by education. I have failed of my purpose, if I have not shown that education is a necessity; that, though it does not supply everything, it forms the necessary foundation for the superstructure, besides furnishing a good many details of that superstructure itself.

Where to Study.

It now remains to examine what facilities exist for the acquisition of this knowledge; and in respect of what I have called the fundamental education of the Optician I will at once frankly admit that in my opinion, putting aside consideration of time and money, the best education for an intending Optician is that offered by a good English

public school. This should be followed up at a university by the further study of mathematics and science. A subsequent year in Germany and six months in France would give the student facility in the two languages, with opportunities for technical study. After which he would start his business career with the best possible fundamental education as its most valuable asset. But I recognise that here and now this advice is for most of you in the nature of a counsel of perfection, though in other countries where education is better organised such a course would not be out of the ordinary range.

Perhaps we shall get a more practical view of our subject if we go to the other extreme and imagine a lad entering upon his business career straight from an elementary school. How is such an one to acquire the knowledge that is necessary to a capable Optician. If he enters an Optician's shop, in whatever capacity, he will have opportunities of handling goods and picking up knowledge; opportunities which are of great value, but by themselves insufficient. He must supplement them with study; and I would advise him till he is eighteen to devote as much as he can of his spare time to the study of mathematics first, and also, if possible, of some literary subject. He should join a good evening school, preferably at one of the polytechnics or institutes which are within reach of most Londoners, and, I doubt not, of the inhabitants of all our principal towns. At eighteen he should test his knowledge at an examination; the best I know of at present is that of the Spectacle Makers Company. I hope, in time, that the Court of the Spectacle Makers Company will arrange for their examination to be taken piecemeal as a matter of course, as indeed, I believe it can already be taken informally. If the examination is successful, the student Optician should then start on the study of physics in general and optics in particular. He will find courses of lectures at King's College, at the polytechnics, and at various other institutions scattered over the town; but he must discriminate. It is a bold thing to say, but it is my conviction that from the Optician's point of view the ordinary lecture course on physics or on optics is of very little use. It is based on academic requirements. Time and energy are frittered away on branches of the subject that are unimportant, while the really valuable part is disposed of in one or two evenings. I think the reason is a failure to recognise the requirements of the shopkeeper. If I thought my voice could reach the authorities that organise these matters, I should like to put in a strong plea for the shopkeeping Optician. He is a numerous class, and is as desirous as

any of studying the technicalities of his trade. The matter may be regarded as one of commercial policy. I can, indeed, conceive of no factor more conducive to the development of commercial enterprise in the trade than the technical knowledge of the shopkeeper. What the Optician chiefly wants is a thorough knowledge of the laws of reflection and refraction. He should know and *see* the action of lenses and prisms singly and in combination. He should be saturated with the formulæ that pertain to them. And his knowledge should be of a kind, not only to enable him to produce a formula in answer to a question in an examination paper; but it should be of the nature of that possessed by a good workman, who knows his tools, foresees the work each one will do, is familiar with its good qualities and its short comings (or, shall I say, aberration), and uses his knowledge almost by instinct, or, at least, without any conscious mental effort. Some knowledge the optical student requires of the nature and properties of light, of the problems and phenomena of interference, diffraction and polarisation, but for the most part a mere nodding acquaintance with these subjects will suffice; while of the other his knowledge must be intimate and thorough. I should frankly confess that these remarks are based on an experience of the facilities that existed in London some ten or fifteen years ago. I let them stand, for I believe that they are still generally applicable. But it is only right to make an important exception.

The Northampton Institute.

For the purposes of this paper I have been examining the prospectuses of several polytechnics and institutes, and I am delighted to find at the Northampton Institute a special course of classes for Opticians, which, if one may judge by the syllabus, is exactly what the trading Optician requires. There is a class on applied optics which seems to cover the whole ground; I am tempted to add, and a little bit more; but I have no doubt that the more abstruse optical subjects bulk more largely in the syllabus than they do in the lectures. However that may be, I would advise students that attend that course to give their first and best attention to that part of the subject which I have already indicated, and until that is thoroughly mastered, to keep the rest at a distance. The laboratory work in connection with this class, organised as it is by our fellow member, Mr. Drysdale, whose work we know and appreciate, ought to be most valuable. Then there is a class on so-called visual optics, a subject for which in my day

there were no means of study other than those which were afforded by the medical schools; and even then the subject was necessarily approached from a different point of view. In the practical class connected with this course the student should learn methods of lens work connected with spectacles, which every Optician should do for himself, as a chemist weighs and mixes his own drugs, such as centering, setting axes of cylinders and prisms, and so on. In the laboratory he need only study the methods, facility he will get by practice in his own shop. He should also find there the best tools and the best methods of performing minor manual work connected with spectacle lenses, as shanking, cutting, edging, drilling, balsaming, greying, etc., so that he can direct these operations at home. I would venture to hold out to the teachers at these classes as the object to aim at, not the manual dexterity of the students, but the familiarising them with the best methods; *e.g.*, in edging, the quality of the stone and the best working speed. An ideal laboratory of this kind should know and study all methods and tools and advocate the best; it should be fitted with apparatus suitable to small workshops, and even I should like to see its power supplied by a small dynamo, such as could be used by the average Optician.

Lectures on Scientific Instruments.

But with regard to these Northampton Institute classes, I want especially to call your attention to the course on optical and scientific instruments. The arrangements for this class seem to me altogether admirable, the different instruments are taken seriatim, and laboratory work follows the order of the lectures. One can imagine no course of instruction better adapted to the technical requirements of the Optician. If we may judge by the syllabus, methods of testing instruments are dealt with as well as the principles of their construction. This is as it should be, and I hope the work is carried out practically in the laboratory. I have no doubt but that it is. I would suggest also that so far as possible in the laboratory illustrations of, and experiments in the work expected of each instrument be given, *e.g.*, in connection with the microscope, the more critical work of the physiologist, the pathologist, the petrologist, the analyst, the brewer and others who use the instrument professionally should be actually shown, and apparatus and conditions best adapted to each variety of work studied. If I have anything to add to this note of appreciation it would be in the shape of a suggestion that next year, if the course is repeated, the

advisability be considered of including among the instruments the barometer and the thermometer with their variants: they form a class of instruments in which nearly all Opticians deal, and in connection with which a good deal of technical knowledge is desirable.

The S.M.C. and the B.O.A. Exams.

I have said I think enough to emphasise my high appreciation of the facilities for study that are offered to the Optician by the Northampton Institute. I cannot do better than commend these classes to the notice of those of you who are students, or who control the actions of students present or prospective. Those who are out of reach of the Northampton Institute should acquaint themselves with the nature of these classes, and use whatever influence and opportunity they may have to get similar classes started in their own centres. That way lies prosperity and success to the Optician's trade throughout the country. But it is not sufficient that these facilities should be provided; we must take advantage of them. And in that connection I should like to add a word about the examinations of the Spectacle Makers Company and the British Optical Association. I think from this point of view you see these examinations in their right proportions. It is almost a platitude to say that an examination is of no good in itself. But we can see that from the point of view of the education of the Optician, these examinations serve two very useful ends. Firstly, they tend to attract to the trade young men with brains, and secondly, and chiefly, they act as incentives to young men that are in the trade to study. The examinations present a certain achievable standard to be worked up to, and, human nature being what it is, the prospect of a definite goal, even though it be elusive, like the carrot to the donkey, acts as an inducement to proceed. I say this of the Spectacle Makers Company's examination, and it will explain why some of us are so desirous of keeping the so-called full examination as the standard of success. I say it, too, of the British Optical Association's examination, though with less conviction; for the members of that Association would themselves be the first to admit that their subjects are not so comprehensive, nor from the point of view of general optical education, so useful, as those of the other examination.

Gentlemen, at the commencement of this address I promised a sketchy treatment of my subject; at its conclusion I feel its inadequacy even as a sketch. The subject is a great one, scarcely to be

dealt with in so short a paper. But perhaps some of you will consider the half hour, during which you have listened to me, not altogether wasted, if I have helped to convince anyone of these three necessities: The necessity of a technical education to the trading Optician; the need of a sound fundamental education on which to build the technical education; and, in directing the course of that technical education, the necessity of considering its practical ends. (Loud Cheers.)

The following remarks were made at the conclusion of Mr. Dixey's paper.

Dr. Walmsley: Gentlemen, the President's address is not a subject for discussion, as we know, like a paper; therefore I do not rise for the purpose of criticism, but for a far pleasanter duty, and that is to move a very cordial vote of thanks to our President for the address to which we have just listened; and in making this motion I think we may congratulate ourselves upon the fact that he has certainly chosen a subject which is second to none in importance, and one result will be to make the members think over the subjects which have been alluded to. I move that the cordial thanks of this meeting be given to our President for his address, and that it shall be printed in our transactions. (Cheers.)

Mr. Aitchison: If you will allow me I should like to have the pleasure of seconding that vote of thanks, particularly because the address of our President to-night is one which is really not open to criticism, as it touches a subject which our previous Presidents have kept entirely clear of. The education of the Optician is undoubtedly the subject which has been the cause of the Spectacle Makers Company taking up the work that they have, and I believe really that was the cause of the formation of the Optical Society. (Hear, hear.) I believe this question of the education of the Optician is the object which we all have at heart, and our President has approached the subject in such a broad spirit, and at the same time he has driven the subject home in such a way that I believe what we have previously done has really only been like throwing seed broadcast. Fortunately, some of those seeds have taken root in the work of the Northampton Institute. But to-night I believe our President has actually planted the seed, the growth of which it will be impossible to stop. With regard to one or two of his points, although, of course, the address is not a subject for discussion, I should like to be allowed to make some comment. As to the education of the Optician, it seems to me that

one fault at present is that the greater number of the new members of the trade or profession—I prefer to call it trade—seem to have drifted into it unconsciously; it is not a trade that they have been brought up to by their parents. I know there are a certain number of the old-established houses who bring up their sons to follow them in the business; but the majority of the new men, those who have passed the examinations of the Spectacle Makers Company, are those who, as it were, have taken up the trade as an afterthought. In regard to the education of the Optician, it is quite a question whether a good retail Optician can be made out of a boy who has passed through a public school and then gone to a University, and, added to that, had a year in France and Germany, because he has then got to the age of two or three-and-twenty. Abroad, things are different, because at the age of twenty or so a man has to pass his two or three years of military service. In England, as a rule by that time a young man going into business has already become settled more or less, and if he has not obtained some practical business experience by the age of twenty, he has a tendency to lose the power of acquiring those habits which are necessary in an ordinary retail business. Consequently, that leads me very much to favour the idea of following up the form of education which we have started in connection with the Northampton Institute and other kindred institutions. It seems to me, after a lad has passed through a public school education, if he has a chance of getting a certain business knowledge part of the day, he can, in his spare time, attend such classes as we have been suggesting, and in this way he will stand a very much better chance of being able to make a successful career, by the combination of a business knowledge and the scientific knowledge which we consider necessary for the training of an Optician. (Cheers.) I have much pleasure in seconding the vote of thanks which has been moved by Dr. Walmsley, and I would ask you, gentlemen, to signify your approval in the usual way. (Applause.)

The Chairman: I am very much obliged to you, gentlemen, for the cordial way in which you have accepted the motion. I am afraid my paper was very dry indeed. ("No, no.") But after all, it may have afforded, here and there, an interesting subject for your further consideration. If it meets with your further consideration, and if you will help to think out some of the problems that it suggests, it will have entirely served its purpose. I suppose now that I am in the Chair I ought to be the most formal in the room; I am very much tempted to discuss one or two points that have been raised, but I will try and refrain

from doing so. However, I will mention one little matter, not by way of discussion, but by way of explanation. If the seconder of the motion which you have just carried expressed his agreement with some of the points in my paper, I can hardly, myself, express astonishment. It is a curious thing that about three weeks ago, when I was cudgelling my brains about this address, I received a letter from the gentleman who seconded this motion, a very long one, which I read and replied to to the best of my ability. I then put it away in one of my pockets. I then went on cudgelling my brains, and eventually got my subject together and wrote it out. When I had done that I had a sort of idea that I had read something else on the same subject before, and happening to take hold of this letter I read it again, and was horrified to find that my paper was little more than an amplification of the letter I had received! I merely mention this by the way—I do not want to make this particular gentleman responsible for everything that I have said —(laughter)—but I mention it to explain the leniency shown with regard to some of the observations I made in my address. (Cheers.)

THE RELATIONSHIP BETWEEN ACCOMMODATION AND CONVERGENCE IN AMETROPIA.

By Lionel Laurance, *Member.*

Read before the Optical Society on April 25th, 1901.

ON being asked, last week, to read a paper before this Society, the difficulty which immediately presented itself was to find a subject that would be of sufficient interest to the members. I asked the President, Mr. Dixey, to suggest something about which I might be able to talk, and it is to him I am indebted for the suggestion that the paper which I am reading to-night should be on the subject of the relationship that exists between convergence and accommodation in ametropia.

As you all know, emmetropia is the condition of an eye in which, when accommodation is at rest, parallel rays come to a focus at the retina. Thus for vision at infinity in emmetropia no accommodation is exerted, yet this is, indeed, not strictly true, since a typical emmetropic eye when thoroughly atropinised usually exhibits about one diopter of hypermetropia.

The condition of orthophoria is one which obtains when the eyes in their primary position—that is with the motor muscles at rest—have their visual axes parallel to each other. As a fact, it is rather an unusual condition for such to be the case, generally there is slight divergence or convergence of the visual axes, if no effort is made to maintain binocular single vision, but we take it that in a pair of orthophoric emmetropic eyes neither accommodation nor convergence is exerted when the eyes are adjusted for vision at infinity.

When the eyes are accommodated for some near point, if the one eye is occluded, there is usually divergence of the visual lines for, although, the accommodation is accompanied by convergence, yet the latter does not correspond in quantity to the former unless fixation of the visual lines takes place. Such deviation is a physiological condition.

So it appears, as has just been mentioned, that convergence has three

different components, namely (*a*) the initial or primary convergence —positive or negative—which results from the latent divergence or convergence of the visual lines when the motor muscles are at rest, and which comes into force when the eyes are adjusted for infinity; (*b*) the convergence which accompanies and is determined by accommodation, and (*c*) the supplementary convergence which must be exerted also in near vision, so that fusion of the two retinal images may be made. It is, however, not my intention to discuss to-night these various components of the convergence function, but to take it as a single action.

Accommodation and convergence accompany each other, that is to say, in ordinary eyes the one function cannot be exerted without the other. At the same time they can be disassociated more or less completely, as is shown by the fact that if accommodation be paralysed by a cycloplegic, convergence is not appreciably interfered with, and this is so, although to a less extent, if accommodation is rendered useless by the interposition of positive lenses before the eyes. If convergence is prevented by prisms bases-in, accommodation can still be exerted; or if the eyes observe an object at a distance, when convergence is unnecessary, the object can still be seen through concave lenses, by means of accommodation. In fact, we have special terms —namely, the relative amplitude of accommodation and convergence, to express the amount that either function, can be made to exceed or fall short of the other when a given quantity of that other is exerted.

When the eyes are adjusted for some point nearer than infinity, both accommodation and convergence are brought into action, because more refractive power is needed and because the two visual lines meet on the median line at the point of vision. We express the amount of accommodation that is exerted for vision at the given point as so many diopters, the number of diopters being equal to the power of a cx. lens whose focal distance is the same as the distance of the object viewed; the amount of convergence exerted is expressed as so many meter angles, the number of which is the same as the number of diopters of accommodation. Thus, at 33 cm. there is exerted 3 D accommodation and 3 M.A. convergence. We can say then, that the amount of accommodation and the amount of convergence that is exerted by a pair of emmetropic eyes is the same and is governed solely by the nearness of the object viewed, and we may also presume that, the eyes being orthophoric, the amount of the efforts that are

made to produce the two functions are similar and equal—at least we may take this presumption as a starting point for our consideration of the relationship existing between these two muscular systems of the eye.

Let us see what governs the exertion of accommodation and convergence, that is to say what governs the amount of these functions produced by a given effort. As regards the accommodation it depends chiefly on two things:—One is the flexibility and resiliency of the crystalline lens, and the other is the effective power of the ciliary muscle. When a person is young I can understand that for a given contraction of the ciliary muscle, a greater amount of accommodation results; when a person is older there is less response on the part of the lens, and a smaller amount of accommodation results from a certain effort. Again if the ciliary muscle is strong, or its fibres are numerous, less effort is needed for producing a certain amount of contraction and more is needed if the muscle is weak. Thus although the amount of accommodation exerted may correspond with that of convergence, yet the effort of the former may be greater or smaller than that of the latter, owing to conditions connected with the accommodative apparatus of the eye. Concerning this I shall have a little more to say later on.

The meter angle is rather a vague term since the exact amount of convergence, expressed in degrees, exerted when the eyes are converged, say, one meter angle varies with the interpupillary distance; the meter angle being that angle whose sine is measured by half the interpupillary distance; and the sine, of course, varies with the angle itself.

The farther apart the eyes the more actual convergence is exerted when the eyes are converged for a certain distance; if the interpupillary distance is 64 mm., the M.A. = 1° 50′ for each eye, if the interpupillary distance is 58 mm., the M.A. = 1° 40′.

Thus we see that apart from all other considerations, the greater the interpupillary distance the greater must be effort of convergence made, that is while the angular deviation from parallelism may be the same, the amount of convergence, expressed in terms of the M.A., varies for a given effort. We may, however, disregard the small differences resulting from variations in the interpupillary distances, and consider that with eyes which are orthophoric, emmetropic and not presbyopic the efforts of accommodation and convergence made for vision at a given distance are equal and also harmonious in effect.

If the primary position of the visual axes is that of divergence, effort on the part of the internal recti is needed for fixation at infinity, if it is that of convergence the external recti act so that vision at infinity may be single, so in the first case it is probable that a greater, and in the second case a smaller effort of convergence for near vision is needed, although the motor muscular system may still be considered orthophoric.

But should there be any insufficiency of the internal recti (exophoria), while the amount of convergence that is required for fixation at a distance of 33 cm. is three meter angles, the same as if there were no such insufficiency, obviously the amount of effort which is needed in order to produce these three meter angles is greater than if the internal recti were normal as to their power.

Similarly, if there be insufficiency of the external recti (esophoria), although for 33 cm. three meter angles of convergence must be exerted, yet the effort needed is clearly less than if the internal recti were not stronger than the external, thus we see that in emmetropic eyes there can be want of harmony between accommodation and convergence ; there can be conditions of the motor muscles which involve treatment in some way—by relieving prisms, by training or by operation ; there can be the conditions where, with corresponding efforts, the accommodation produced is not sufficient. Here a greater effort of accommodation than of convergence is required, this, of course, is the condition of presbyopia.

Hypermetropia is the condition of the eye in which parallel rays tend to focus behind the retina, owing to one of two conditions ; either the globe is too short, relatively to the focal length, or the refractive power is deficient in respect to the axial length of the globe.

The two conditions are of course precisely the same in effect, and although the general cause of hypermetropia is the fact that the globe of the eye is abnormally short as compared with the average eye, yet it does not follow that the eye is hypermetropic on account of this deficiency of length. For were the refractive power in proportion, the length of the eye could be indefinitely short or indefinitely long, and yet be emmetropic, in consequence of parallel rays coming to a focus at the retina when accommodation is at rest. It is the fact that the retina is situated at the principal focal distance of the eye which constitutes the condition of emmetropia.

Similarly, the condition of myopia is that of an eye in which the globe is too long in relation to the focal length, or the refractive power

is too great for the axial length of the globe. Here again, we see that the two conditions are precisely the same in effect, although it is recognised that myopia is principally due to the fact that the eye is abnormally increased in length.

We can, therefore, disregard the anatomical conditions and regard hypermetropia and myopia as purely refractive conditions, in which, in the first case, the static refractive power is deficient, and in the second case, it is in excess of what is required for focusing at the retina parallel rays of light. In hypermetropia, owing to the deficiency, and in myopia, owing to the excessive quantity of refractive power, parallel rays focus in the first case behind, and in the second case in front of the retina.

When the eyes are adjusted for a near point in H, there is exerted as many more diopters of accommodation, than in emmetropia, as there are diopters of hypermetropia, provided always that such exertion is possible ; while in myopia there is exerted as many diopters less, provided that clear vision is possible—that is to say, if the position of the object is not beyond the far point of the myope. At the same time the amount of convergence needed—expressed in terms of the meter angle—is the same as in emmetropia.

Now let us consider the case where there is ametropia and insufficiency of the horizontal muscles. Suppose a person were hypermetropic 2 diopters, he would, when reading without glasses at a distance of 33 cm., exert accommodation to the extent of 2 D more than would the emmetrope ; he would need to exert 5 D while at the same time the amount of convergence would be three meter angles.

Here the amount of accommodation demanded is in excess of that of convergence ; and this is usually the case, in hypermetropia. We consider that asthenopia results from this fact, we say that accommodative asthenopia is the result of the demand for accommodation in excess of that for convergence ; and as a result of the excessive demand we find, usually associated with H, relative insufficiency of the external recti (esophoria) which is brought about by over development of the internal or perhaps actual weakness of the external recti owing to their being constantly brought into play in order to restrain or prevent the eyes from converging to an extent equal to that of accommodation.

Were convergence exerted equally with accommodation in hypermetropia of 2 D, we should find the eyes accommodated for 33 cm. while converged for 20 cm., so that there would be strabismus or squint. I presume that every hypermetropic child elects between

monocular and binocular vision and, so to speak, decides on the binocular if it is sufficiently clear and painless and on the monocular if it is either clearer than the binocular or less painful, or because he cannot dissociate the linked functions of accommodation and convergence. Thus, in the typical case of hypermetropia we find that there is easy convergence and difficult accommodation (because so much of it is required). It is hard enough for the eyes to accommodate in excess of convergence even when the horizontal muscles are in perfect equilibrium and it is still more so when convergence is relatively easy.

If the external recti were not relatively weaker and we designated the amount of effort needed for convergence at three meter angles by the letter x, then, if the internal recti are comparatively very strong the effort must be less than x. Again, if the effort made for 3 D of accommodation be designated by the letter y, then the 5 D needed in hypermetropia of 2 D is more than y.

On the other hand, habit has caused the accommodative power to become very responsive so that a larger amount of accommodation results from a given effort. Thus it is that the disproportion between the accommodation and convergence in hypermetropia is not solely and really represented by the number of diopters of error, but may be much greater on account of the relative muscular weakness engendered by the error itself, or much less owing to facile accommodation.

Now the cure for asthenopia, which is brought about by inequality of effort between accommodation and convergence, must be to equalise these efforts, and this we can do by giving a cx. lens, which possesses the property of increasing the refractive power of the eye, so that the amount of accommodation which is needed for vision at any given point is as many diopters less, than would otherwise be the case, as equals the number of diopters in the lens.

By means of the cx. lens we reduce the effort of accommodation to the same scale as that of convergence, and so restore what is called "harmony" between the two functions; and since there is so great a difference between the two efforts it is necessary, in selecting the corrective lens for a case of hypermetropia associated with esophoria, to give the strongest + sph. with which distant vision is clear; as a rule this lens is that one which fully corrects the manifest error (except perhaps in young people). Later in life, the amount of accommodation that is produced by a given effort, being smaller than in youth, we find that a stronger + lens is needed, the proportion of the total hypermetropia which is then manifest being also greater.

The cause of asthenopia is not, in my opinion, that unequal quantities of accommodation and convergence are demanded in ametropia, but because the efforts that are made, in order to see clearly and singly, are unequal and perfect comfort results from the lenses selected only when the efforts are equalised and not necessarily when the amounts produced of each function are the same.

We often hear that ex. lenses fitted under the influence of atropine are not comfortable when the effects of the drug have passed away. Whereas previously the effort of accommodation was necessarily greater than that of convergence, with the glasses the effort of accommodation has to be smaller, with the result that the eyes are as painful as, or even more so than, before. By persistent wearing of the glasses the subject manages to be able to use them, that is to say, the muscles become trained to act in accordance with the glasses, but perhaps better results would have ensued had the glasses orginally given not been of so full a power.

It is frequently found that a certain + lens is the strongest accepted by each eye separately, but that the two eyes, acting together, accept still stronger ones. The cause of this, I take it, is that when one eye is occluded convergence to a nearer point is possible without diplopia ensuing, and this convergence to a nearer point than ∞ results from the relatively great strength of the internal recti. When the two eyes are fixed at infinity—6 meters—convergence to a nearer point is no longer possible: therefore, accommodation is not so actively exerted, and the degree of manifest hypermetropia is greater. This is the true measure, *i.e.*, the strongest + sph., with which vision is the best possible, that is accepted by each eye when both are engaged on the act of vision. Any difference between the two eyes having of course been rectified during the monocular test.

If the condition of exophoria (insufficiency of the internal recti) is associated with H, we find that not only is accommodation difficult but convergence is also, so that it may well happen that the efforts for seeing singly and clearly at any given point are the same, and no asthenopia results. Such eyes require no ex. lenses; the hypermetrope is perfectly happy without any artificial aids to vision, until he arrives at that time of life, when an effort of accommodation equal to that of convergence, when made, does not produce a sufficiency of accommodation for good vision at the point of fixation, and one of two things must result; either he sees indistinctly, or he has to make a greater effort of accommodation than convergence, and asthenopia

results. In testing such a person—each eye separately, we find that a certain + sph. is the strongest lens accepted, and with this the vision of each eye is made quite clear, but when the two are used together vision at once becomes exceedingly confused, because the eyes are accommodated for a point nearer than that for which they are converged, or the vision is very uncomfortable, for the reason that the effort of accommodation now demanded is smaller than that of convergence—previously the effort of accommodation was greater than that of convergence. Good and comfortable vision results if the correcting lenses are reduced in strength.

Then we can apply certain rules to the correction of hypermetropia. When esophoria is associated with it, we must give the strongest + sph. lenses, and even then I believe rather in under-correcting than in over-correcting; I would, when in doubt, prefer to give something weaker rather than something stronger, for at most this only means that a rather stronger lens must be given a little later on, say in a year or two's time, and I think that it is quite unnecessary to put customers through a period of transition from discomfort to comfort, which in plain words means making a person learn to adapt his eyes to suit the lenses. When there is exophoria we should give weaker lenses, and may be very considerably weaker lenses, than those whose power represents all the manifest error.

These rules apply specially to adults, or let us say to people over sixteen years of age. Under that age, I think that Opticians would do well to consider that thorough paralysis of the accommodation is necessary in order to ascertain and measure the refractive condition, not necessarily in order to correct the total refractive error (except any existing astigmatism) but so as to be able to more exactly ascertain the exact power of the lenses from which will result good and painless sight.

So far as I know we have no means of learning how much of a function results from a given effort; we can only guess at or instinctively gauge it. In order to find those lenses which will cause the effort of accommodation to be similar to that of convergence, we have laid down the rules that strong ones should be given in esophoric H, and weak ones in exophoric, and practice and experience—almost instinct—only can help us to decide as to the exact power of the lenses, which should be given in any particular case; and even then they may or may not be the most suitable ones.

Coming to the condition of myopia, we find a somewhat similar

state of affairs. Owing to the nearness of the point at which, in myopia of fairly high degree, objects must be viewed, the amount of convergence demanded is great in quantity, and the effort is relatively still greater owing to the peculiar shape of the globe and to the weakness of the internal recti, so commonly associated with myopia; this weakness being the result of over action. At the same time, the amount of accommodation demanded is nil, as the myope quite commonly reads at his far point, so that the disproportion between the efforts of the two functions is very marked. So great indeed is the disproportion between them that, to relieve the asthenopia which results therefrom, as well as on account of the actual weakness of the internal recti, divergent strabismus often results.

In cases where strabismus does not result, in the typical case of myopia we find insufficiency of the internal recti (exophoria) with asthenopia, on account of the unequal efforts of accommodation and convergence. We correct such cases by giving certain cc. lenses which make distant vision clear, and certain other cc. lenses for reading or constant wear, the power of the latter being somewhat weaker than those for distance. We do this because we find that the accommodation itself is deficient in myopia, so that less of it results from a given effort. Were the accommodative power equal to that of the emmetropic or hypermetropic eyes, we should give as strong glasses for reading as for distance. For instance in a case of myopia 4 D, the internal recti being weak, the effort made for convergence at 33 cm. is a certain amount which is greater than if the internal recti were normal, a similar effort of accommodation produces not more than 3 D, as would occur if the accommodative power were normal, and most likely not even 3 D, but say 2 D so that the power of the glasses required for reading or constant wear should be 1 D less than that for distance.

Then in exophoric M, the proper glasses for close work and constant wear should be those which are as nearly as possible of the strength of those which are a measure of the M as indicated by the distance test. In short, we must encourage the use of accommodation so as to equalise the efforts of accommodation and convergence, but the glasses must not be too strong.

In cases of myopia where there is esophoria (insufficiency of the external recti), convergence being easy, and little effort needed, if we were to give, so to speak, strong cc. glasses for reading purposes, we should cause the effort of accommodation to be greater than that of

convergence and the eyes would be painful, so that it is advisable to reduce the glasses, needed for reading at 33 cm, 3 diopters below what is used for distance. Thus no accommodation is demanded for reading purposes; and the effort more nearly corresponds to that of convergence. Generally in this condition the myope prefers to use no lenses constantly, if he does he complains of pain and dazzling if they are at all nearly a full correction. The rule then that can be applied to myopia is, when there is exophoria, permit accommodation to be used for close work, and, when there is esophoria, do not allow it to be used.

Most of us have had the experience of meeting with, or reading about, hypermetropes who had been using cc. lenses and myopes using glasses very much too strong, and this apparently with comfort. The reason seems clear enough—with them in front of the eyes, the effort of accommodation made was equal to the effort of convergence. I do not pretend to say that the use of such cc. glasses is proper or should be permitted, but I certainly do know that very frequently cc. cylindricals give greater comfort than cx., or a simple + cylindrical is more satisfactory than a + sphero-cylindrical, the extra accommodation then exerted rendering the efforts of the two functions more equal. In such cases frequently it is possible to suppress accommodative action, and we might be told that such should be done, as although perhaps uncomfortable at first the additional + power would ultimately prove beneficial, but I am exceedingly doubtful about this point.

Whether, on testing the muscles, we find them apparently orthophoric, esophoric or exophoric, we do not know how much convergence results from a given effort; we can only conclude that less results if the internal recti are weak, and more if they are strong; nor do we know how much accommodation results from a given effort of that function; only we know that in hypermetropia, the amount produced is large, and that in myopia it is small, owing to the respective conditions of the ciliary muscles. It is this which enables the typical hypermetrope to be comfortable with a partial correction of the total error, notwithstanding his esophoria. And this same thing causes the typical myope of high degree to be unable to use any accommodation when reading, notwithstanding his exophoria—no amount of effort seems to produce any accommodation in the very highly myopic eye—the function seems to be almost entirely lost owing, no doubt, to the fact that it has been not exerted for so long a

time. Also the amount of accommodation produced in youth is very much greater for a given effort than it is later in life, owing to the flexibility of the lens in youth and its hardness later on. It is this latter fact which enables the young hypermetrope to do very well without cx. lenses, while later in life he requires them; and this is true, no matter what may be the condition of the motor muscles. In youth he makes, for reading at 33 cm., a certain effort of convergence, which is accompanied by a similar effort of accommodation, and the amount of each function produced causes vision to be clear and single, so that he is quite comfortable; later in life, the amount of accommodation produced by the same effort is not so great and he has to make a supplementary effort of accommodation in order to obtain clear vision, so that pain results. He then requires cx. lenses, whereas he did not need these when he was younger, notwithstanding the fact that it is possible that the amount of hypermetropia was then greater than it is at the time when he resorts to lenses. So also in myopia, later in life concave glasses previously used for near vision, and which caused accommodation to be exerted, must be reduced in power.

In emmetropia, too, a similar condition results, the emmetrope at 40, when he makes an effort which results in three meter angles of convergence obtains with a similar effort of accommodation three diopters of additional refractive power, and sight is clear and painless. At 45, with the same efforts, convergence is as it was at 40, but the amount of accommodation produced is less owing to the hardening of the crystalline lens. From the supplementary effort of accommodation, by means of which he is enabled to see, results the asthenopia complained of in incipient presbyopia. Later on, he cannot even see to read at all, because he cannot, try as he may, produce sufficient accommodation. The true correction for presbyopia is that dioptral lens which represents the difference between the amount of accommodation, which is needed for vision at the reading place, and that which is produced by an effort of accommodation equal to the effort of convergence.

The theory that we must in presbyopia decentre cx. lenses inwards or give prisms bases-in so as to relieve convergence equally with accommodation is, in my opinion, quite erroneous; the glasses should be centered exactly to the visual axes when they are directed to the reading place.

Relief is not obtained by reducing the amount of convergence that need be exerted—the internal recti are not necessarily weak—as well

as reducing the amount of accommodation demanded, but by restoring harmony between the necessary efforts of the two functions: and on the same principle, I do not think that we need usually decentre ex. and cc. lenses in order to relieve the muscles in hypermetropia and myopia. We obtain comfort, in the manner I have indicated, by means of sphericals which cause the efforts of the two functions to be similar.

Only, indeed, prismatic power may be indicated when, by means of sphericals, in any case of refractive error or of depleted accommodation due to age, harmony between the efforts cannot be produced, since we are limited on the one side by the point of no correction, and on the other by full correction.

We cannot do more in esophoric hypermetropia and exophoric myopia than give an absolutely full correction; if, then, vision is painful, prisms must be combined with sphericals.

Again, in exophoric hypermetropia and esophoric myopia, conditions extremely difficult to treat satisfactorily, we cannot go beyond giving no correction, and if vision is not then possible, sphericals must be applied and supplemented with prisms. Such cases are, however, rare.

If in presbyopia with latent convergence we give + 3 D lenses for reading at 33 cm., and asthenopia still obtains, the external recti must be aided; if there is latent divergence and with no lenses, print at 33 cm. cannot be read, + sphericals must be supplied, in order that vision may be possible; and if they aggravate the muscular trouble, prisms bases-in must be combined therewith.

Prisms bases-out, weaker concaves and stronger convexes relieve insufficiently of the external recti. Prisms bases-in, stronger concaves and weaker convexes relieve insufficiency of the internal recti.

It will be seen that the subject matter dealt with, when one commences to dive into it, is of much complexity and has many ramifications, so that a simple short paper cannot pretend to do justice to it. I therefore trust that the members of this society will extend their indulgence to me, for the inadequacy of its treatment, and in conclusion, I must confess that there are many points concerning accommodation and convergence, and their linked actions, which are involved in obscurity—or, at least, it seems to me to be so.

THE ASTIGOMETER.

By H. M. Selfe, *Member*.

Read before The Optical Society on June 20th, 1901.

MY subject to-night is the "Astigometer," and since I have had such a short time to prepare it I must beg of you to excuse imperfections, and set me right where I am wrong, for no doubt there are those present who could handle the subject far better than I. You see I am neither a mathematician nor an optical expert, but (like many of my relatives) I have two eyes which are somewhat astigmatic (axis vertical in one eye, oblique in the other). So with the trial case in front of me I was testing my sight and was rotating two cylinders, in the manner of a Stokes' lens, when it occurred to me that such an apparatus, if easily and quickly manipulated, might be of service. I conceived the idea that the lenses might be rotated by means of a pushpiece, with a graduated spiral slot, and drew out my design. That week's Optician arrived the same evening, and in it, strange to say, was part of a lecture (or the whole, I am not sure which), given by Professor Sylvanus Thompson.

There he explained a "Stokes' lens" and gave directions for an improvement in the grinding of the lenses as follows: *Each* lens should be ground with a minus and plus surface (that is a — on one side and a + on the other) of equal power, but with axes at right angles. In this case the axis of the combination will be constant.

Now, Sir, you can imagine that my intent in carrying out the idea was doubly strengthened, and here in this "Astigometer" is the result, after much time and labour.

I coin the word "Astigometer" in order not to clash with other ophthalmic instruments.

There was some doubt as to whether we could get it manufactured, so I next had to apply myself to machinery for the same.

Now the instrument, when set to zero, has its lenses as illustrated

in fig. 1. The two + powers are at right angles (thus making it equal to a + sph.) and these are neutralised by two similar — powers; so that when the two lenses are rotated in opposite directions through 45° the two + powers are horizontal and the two — powers vertical, 2·50 D + and 2·50 D —, making a *difference* of 5 D.

Now I maintain that an instrument giving a graduated cylindricity up to 5 D is a most useful one, and I shall try and demonstrate that its principle is scientific. Kindly remember that although I shall have to go somewhat into geometry (or astigometry, shall we call it), for those who do not care to go into the matter of measurements and foci the thing (the handling of the instrument itself, I mean), is most simple.

If *all* astigmatic eyes had what is called mixed astigmatism, of equal diopters — and + then it would only be to find the most *clear* or most

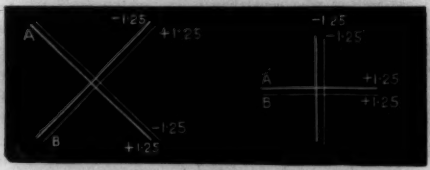


Fig. 1.

blurred lines on a clock face chart, press in the pushpiece and the eye would be rendered emmetropic. But as this is only one out of a number of other conditions, I have to show that it is a simple optical performance to place an eye in that particular condition by means of a + or — spherical, providing the accommodation is passive.

(I might say here that *if* it is proper for others than Ophthalmic Surgeons to test the sight, the same arguments, with regard to spasm of accommodation, latent hypermetropia, or what not, may be advanced against any other method of testing without a mydriatic, for they all *finish* with the trial case. Most certainly if there is any doubt send your customer to an Oculist.)

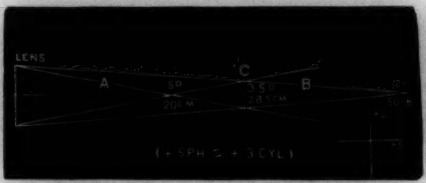
Now I say place that spherical in front of the eye which gives the best vision (this spherical lens will adjust what I call the *mean* power of the eye to the distance of emmetropia), and the instrument will do the rest.

First, with regard to lenses, there is a little confusion arising from the fact that it takes *two* 1 D cylinders to equal a 1 D spherical (two crossed cylinders equal a spherical of the same number), hence in dealing with a lens + 1 sph. ⊃ +2 cyl. we are not handling a curvature of 3 D, but only that of 2 D, its mean power.

I hold a lens in my hand (sphero. cyl.); *what is its power?* It has *two* foci, simply a *line* in each case; its *two* powers are +, namely, 6 and 2, then what is the mean between these? 6 + 2 = 8. 8/2 = 4. Now a — 4 D sph. will neutralise this mean power and will place the lens exactly in the condition equal to mixed astigmatism, and the instrument will exactly neutralise this.

Remember the instrument does *not* alter the *mean* power.

Secondly, take *any* sphero cyl. lens and measure its two focal lengths, call them A and B (see drawing). Now draw two cones to



(Fig. 2.) 2 + 5 = 7. 7/2 = 3½. Mean power + 3·5 D.

represent parallel rays passing through, and continue the lines from A through those of B. If at the point C where they *intersect* you were to cut through these two cones you would find each section *equal* in size, whereas (taking the vertical meridian as the most curved) you find a horizontal line at the focus of A, and a vertical line at the focus of B; the reciprocal of the length to C will be the mean power of the lens. (See figs. 2, 4 and 5.)

Third, place any cyl. or sphero-cyl. lens before a screen at the focal length of its *mean* dioptric power, and the astigometer will neutralise the difference; if this mean power is + a clear image will result. If it is — the instrument will convert it into — sph. of that power.

Now in a simple cyl. say + 5 D, parallel rays passing through the *axial* meridian will continue in a straight line, but those at right angles will come to a focus at a distance of 8 ins. from the lens, will

cross over (being now divergent) and equal the others at a distance of 16 ins. from the lens (see fig. 3), therefore the mean power of a + 5 D cyl. is (D divided by 2) + 2·50 D.

For example, take a + 5 D cyl.; its *mean* power is + 2·50, hold it at that distance (16 ins.) in front of a screen, and the instrument will give a clear image when pressed in to 5 D.

Or for another example, take a + 4 D sph., placed before a screen at the focal distance of a 6 D (6½ ins.); it will now be H 2 D (because it will need a + 2 D to bring it to focus), now add to this + 4 sph. a + 4 cyl. and the image will *not* be elongated. Why? Because the + 4 D cyl. has made the one meridian M 2 D whilst the other meridian (along the ax. of the cyl.) is still left H 2 D. The combined lens has now mixed astigmatism of equal diopters.

In fig. 6 the eye is emmetropic with regard to the mean power (and remember the astigometer does *not* alter the mean power). Now sup-

(Fig. 3.) 5/2 = 2½. Mean power + 2·50 D.

posing the axial length were *shorter* so that the retina were situated *within* this emmetropic distance, what would be the result? The vertical part of the cone would be shorter and the horizontal wider, forming more or less an oval shape; and of course a + sph. would again adjust the round, or more equal part of the cone of rays to the retina.

Now in a simple cyl., say + 5 D, parallel rays passing through the *axial* meridian will continue in a straight line (see fig. 8) but those at right angles will come to a focus at a distance of 8 ins. from the lens, will cross over (being now divergent) and equal the others at a distance of 16 ins. from the lens; therefore the *mean power* of a + 5 D cyl. is (D/2) + 2·50 D.

Example: I hold this + 5 D cyl. at 16 ins. from the screen where the cone is equal in height and breadth, now I place the instrument

close in front, or at the back, of the lens and press in the pushpiece until, at the fig. 5, a clear image is seen on the screen.

As a final example, take *any* combination of cyls. or sphero-cyls., place them before a screen at the focal length of their *mean* power, and the astigometer will at one analyse the combination and give the axis, providing the cyl. power does not exceed 5 D.

Therefore my contention is that the best vision is not where either of the two principal meridians come to a focus but rather *between* these two points, in what is called the "interval of Sturm." If by means of a sph. lens in front of an astigmatic eye you place this mean power at the distance of emmetropia, why you have exactly *balanced* the two defective meridians and V for *all** objects will be as good as it *can* be made unless we use cylindricals.

Or put it this way:—that sph. lens will give the best vision which

(Fig. 4.) 8 + 2·50 = 10·50. D/2 = 10·5/2. Mean power = 5·25 D.

places the *mean* dioptric power of the eye at its focal length from the retina.

To show that my theory with regard to lenses can be applied equally to the eye, I have introduced my *astigometry (?)* in this enlarged drawing (fig. 6), which is accurately to scale. Supposing the eye to have axial length 20 mm., it requires 50 D static refractive power, now to make the lines clear I have given it a very exaggerated amount of astigmatism (32 D). The vertical meridian (and I have all along taken the *vertical* meridian as that of the greatest refraction because in the *average* human eye it is so) focuses to 15 mm. (66 D), the horizontal meridian focuses to about 30 mm. (34 D); therefore it is M 16 D and H 16 D whilst the combined cone at the retina is round. If this eye views the astigmatic chart the lines will all be blurred but *equal*.

It is therefore E with regard to the *mean* power (and remember the

* See the clock-face chart, etc.

instrument does not alter the mean power). Now supposing this axial length were *shorter*, so that the retina were situated *within* this E distance, what will be the result? The vertical part of the cone will be shorter and the horizontal wider, forming, more or less, an *oval* shape, and of course a + sph. will again adjust the round, or more equal, part of the cone on to the retina.

Now if an eye has simple myopic astigmatism 4 D, the *vertical* meridian is out of focus, but as it is the *edges* of a vertical line (the *length* of the line being immaterial), which are focused by the *horizontal* meridian, this eye will see vertical lines clearly; now place in front a — 2 D sph. and all lines should be *equal* although blurred.

You can test this theory by placing a + cyl. in front of your own (emmetropic) eye, making it M in that meridian. Or a — *cyl.* making

FIG. 5.—(— 10 cyl. ⌒ + 20 cyl.
or — 10 sph. ⌒ + 30 cyl.)
+ 20 — 10 = + 10. 10/2 = + 5 D mean power.

it H in one meridian. Then add a sph. of half the amount but of the opposite sign.

Briefly, there is one other point to be considered, the eye may have *irregular* or *lenticular* astigmatism; the ciliary muscle may contract unequally, or the crystalline lens may be out of shape. In either of these cases I contend that a *graduating* cylindrical power will give the very best results. My method with regard to the *best* spherical is only for the purpose of finding the *amount* of astigmatism; for instance it would be injurious to a M eye to *leave* either meridian *over* corrected.

When the refraction of each eye has been estimated, put up the *entire* correction in a trial frame, add as much + sph. power as the eyes will accept *binocularly*, and test the *amplitude of accommodation*.

In testing presbyopic eyes, it is the simplest thing imaginable to hold an extra, weak, + lens in front temporarily ; the *clear* lines on the chart will at once indicate the direction in which the stem is to be held.

In *all* cases put up the cyl. as indicated and *add half* the amount in a sph. of the opposite sign, thus :—

R.E. + 2·00 sph. ast. 1·50 ax. 45°.
— 0·75 „

= + 1·25 sph. ⊃ + 1·50 cyl. ax. 45°.

In testing pure H or M of low degree use straight lines in *one* direction only ; if the lines are *vertical* you are testing the *horizontal meridian.*

Fig. 6.—V vertical and *h* horizontal ray.

Turn the lines round to the horizontal to test the *vertical* meridian. In H the stem must be held *parallel* to the lines, in M it must be held at right angles.

I have been experimenting to see whether I could find an easy practical way of measuring the power of an oblique section of a cyl. by means of the instrument, but shall have to defer that for the present.

In the drawings it should be understood that the two cones are intended to represent the rays passing through the two principal meridians, which of course are at right angles. In fig. 4, both foci being negative, the rays *appear* to diverge from two points in *front* of the lens.